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**NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS**

# **WARTIME REPORT**

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**KNOCK-LIMITED PERFORMANCE OF BLENDS OF AN-F-28 FUEL  
CONTAINING 2 PERCENT AROMATIC AMINES - I**

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## NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Materiel Command

KNOCK-LIMITED PERFORMANCE OF BLENDS OF AN-F-28 FUEL

CONTAINING 2 PERCENT AROMATIC AMINES - I

By J. Robert Branstetter

## SUMMARY

Tests were conducted to investigate the effect of 2-percent additions of 11 aromatic amines on the knock-limited performance of AN-F-28 fuel. A total of 48 aromatic amines are being prepared at the Aircraft Engine Research Laboratory for knock tests. This report presents results for the first 11: aniline, N,N-dimethylaniline, N,N-diethylaniline, N-isopropylaniline, N-butyylaniline, N-methyl-p-toluidine, N-isopropyl-p-toluidine, p-isopropylaniline, 2,6-xylydine, 4-isopropyl-2-methylaniline, and o-methoxyaniline. The knock-limited performance of an AN-F-28 fuel with and without 2-percent additions of each of the aromatic amines was determined in a CFR engine under three sets of operating conditions (including F-4 conditions). The report contains only information on the antiknock effectiveness of the aromatic amines and does not consider other phases of the fuel problem, such as their effect on lubrication and synthetic rubbers.

The results are summarized as follows:

1. These tests indicate that the following aromatic amines (in addition to xylydines) might be considered of interest as antiknock agents: N-methyl-p-toluidine, p-isopropylaniline, and aniline.
2. Of the aromatic amines tested, N-methyl-p-toluidine gave the best rich-mixture performance. Its antiknock effectiveness at rich fuel-air mixtures was nearly twice that of xylydines.
3. At rich fuel-air mixtures the antiknock effectiveness of the aromatic amines in AN-F-28 fuel was both greater and more independent of engine conditions than at lean fuel-air mixtures.
4. All of the aromatic amines tested with the exception of N-isopropylaniline showed pronounced sensitivity to engine operating conditions at low fuel-air ratios. Because of low or negative response, N-isopropylaniline is not of interest.

5. With the exception of the xylidines and p-isopropylaniline, all the aromatic amines tested depreciated the knock-limited performance of AN-F-28 fuel at fuel-air ratios of both 0.062 and 0.070 under F-4 conditions. At the least extreme engine conditions, however, the antiknock effectiveness of the aromatic amines, on a percentage basis, was almost independent of fuel-air ratio.

## INTRODUCTION

The data presented in this report are part of a general program, being conducted at the request of the Army Air Forces, to determine the effects of aromatic amines on the knock-limited performance of a currently used aviation gasoline.

Because of the suggested use of xylidines as an antiknock additive for aviation gasolines, it was thought advisable to knock test a series of aromatic amines. A total of 48 aromatic amines are being prepared. This report, part I of a series of five reports, presents knock data for 11 aromatic amines. In this report no attempt is made to evaluate the amines from any consideration other than that of their effect on fuel knock as indicated by the results recorded on a small-scale engine.

Some of the aromatic amines have been tested in other laboratories prior to the tests for which the results are presented herein. The NACA data, in conjunction with the results of other laboratories, provide a reasonably satisfactory evaluation of the antiknock characteristics of these compounds within the limits of the significance of the engine conditions employed.

This work is being conducted at the Aircraft Engine Research Laboratory of the NACA at Cleveland, Ohio. The data presented were obtained in the period from October to December 1943.

## APPARATUS AND TEST PROCEDURE

Each aromatic amine tested (table I) was distilled through a fractionating column, and a narrow (approximately 1° C) fraction in the middle of the boiling range was selected. The purity of the additives was estimated at 95 percent or more. The preparation and purification of the amines were performed under the direction of Dr. W. T. Olson of the laboratory staff.

The tests were performed on a CFR engine described in reference 1. In the present tests the injection elbow was altered to allow for the installation of an independent "warm-up" fuel system in order that the test fuel could be conserved.

Because a small-scale engine operating at one set of conditions does not predict the full-scale, knock-limited-performance characteristics of a fuel over a wide range of engine variables, three sets of conditions, varying in severity, were used for the present tests.

The three sets of operating conditions are as follows:

	Inlet-air temperature (°F)	Spark advance (deg B.T.C.)	Coolant temperature (°F)
F-4 method	225	45	375
Modification A	250	30	250
Modification B	150	30	250

At each of these sets of conditions, 0- and 2-percent blends of the aromatic amines were tested in one lot of AN-F-28, Amendment-1, fuel on the same day. The value of 2 percent was selected for blending purposes because it represents approximately the amount that would be of greatest interest. Tests of 1- and 3-percent blends would have been useful in extending the data, but limitations in the quantities of the amines available prevented these choices.

#### DISCUSSION OF RESULTS

A bracketed AN-F-28 fuel reference curve (data compiled from several tests made during the course of the project) is presented in figure 1.

The knock-limited performance data obtained on the aromatic amines are presented in figures 2 to 12. Each figure compares the effects of the transition from severe to mild test conditions on blends of 0 and 2 percent aromatic amines and AN-F-28 aviation gasoline.

Table I summarizes the relative power obtained by the addition of aromatic amines. They showed decidedly greater sensitivity for a change in fuel-air ratio under F-4 than under either of the two less severe conditions. When the engine was operated under F-4 specifications, none of the amines increased the knock-limited power more than the base fuel at fuel-air ratios of 0.062 and 0.070 (with

the exception of commercial xylidines at 0.062), however, N-methyl-p-toluidine, p-isopropylaniline, xylidines, and 4-isopropyl-2-methylaniline exhibited desirable rich-mixture characteristics.

The antiknock effectiveness of the aromatic amines approached independence of the fuel-air mixture when the severity of conditions was decreased. When the columns in table I at the inlet-air temperature of 150° F were averaged, an improvement of 1 percent in relative knock-limited power was noted with an increase in fuel-air ratio from 0.062 to 0.110.

Again, when the relative knock-limited powers (table I) were averaged, the amines showed progressive improvement with a transition from severe to mild test conditions except that, at very rich fuel-air mixtures, the severity of conditions had little effect on the relative knock-limited performance. The effect of conditions was most outstanding at lean fuel-air ratios.

In general, p-isopropylaniline and N-methyl-p-toluidine resulted in higher knock-limited performance than both 2,6-xylidine and commercial xylidines and, of the additives tested, N-methyl-p-toluidine gave the highest permissible power at an inlet-air temperature of 150° F at all fuel-air ratios. Also, under F-4 conditions this additive showed marked superiority at very high fuel-air ratios but acted as a proknock agent at lean mixtures. With the exception of 4-isopropyl-2-methylaniline and o-methoxyaniline, N-methyl-p-toluidine showed greater sensitivity to engine conditions than any of the other amines tested.

The indicated specific fuel consumption of the aromatic-amine curves coincided with that of the base fuel on more than half the tests; several additives, however, showed more economy improvements in the rich region than in the lean region. Because sufficient material was not available for check runs, the significance of these differences in indicated specific fuel consumption is questionable.

#### SUMMARY OF RESULTS

From tests of the antiknock effectiveness of 2-percent additions of 11 aromatic amines to AN-F-28 fuel under three sets of conditions in a CFR engine, the following results were obtained:

1. The aromatic amines (in addition to xylidines) that might be considered of interest as antiknock agents are N-methyl-p-toluidine, p-isopropylaniline, and aniline.

2. Of the aromatic amines tested, N-methyl-p-toluidine gave the best rich-mixture performance. Its antiknock effectiveness at rich fuel-air mixtures was nearly twice that of xylidines.

3. At rich fuel-air mixtures the antiknock effectiveness of the aromatic amines in AN-F-28 fuel was both greater and more independent of engine conditions than at lean fuel-air mixtures.

4. All of the aromatic amines tested with the exception of N-isopropylaniline showed pronounced sensitivity to engine operating conditions at low fuel-air ratios. Because of low or negative response, N-isopropylaniline is not of interest.

5. With the exception of the xylidines and p-isopropylaniline, all the aromatic amines tested depreciated the knock-limited performance of AN-F-28 fuel at fuel-air ratios of both 0.062 and 0.070 under F-4 conditions. At the least extreme engine conditions, however, the antiknock effectiveness of the aromatic amines, on a percentage basis, was almost independent of fuel-air ratio.

Aircraft Engine Research Laboratory,  
National Advisory Committee for Aeronautics,  
Cleveland, Ohio, April 17, 1944.

#### REFERENCE

1. Branstetter, J. Robert, and Meyer, Carl L.: Antiknock Effectiveness of Xylidines in Small-Scale Engines. NACA Memo. rep., Aug. 6, 1943.

TABLE I - SUMMARY OF ANTIKNOCK EFFECTIVENESS OF AROMATIC-AMINE ADDITIONS TO AN-F-28 FUEL

[F-4 method: inlet-air temperature, 225° F; coolant temperature, 375° F; spark advance, 45° B.T.C.  
Modification A: inlet-air temperature, 250° F; coolant temperature, 250° F; spark advance, 30° B.T.C.  
Modification B: inlet-air temperature, 150° F; coolant temperature, 250° F; spark advance, 30° B.T.C.]

Aromatic amines (2-percent addition to AN-F-28 fuel)	Relative power = $\frac{\text{imep (aromatic amine plus AN-F-28)}}{\text{imep (AN-F-28)}}$											
	Fuel-air ratio											
	0.062			0.070			0.090			0.110		
	F-4 method	Modification A	Modification B	F-4 method	Modification A	Modification B	F-4 method	Modification A	Modification B	F-4 method	Modification A	Modification B
AN-F-28	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Aniline	-----	1.14	1.11	-----	1.07	1.10	-----	1.09	1.13	-----	1.11	1.10
N,N-dimethylaniline	-----	.99	1.01	-----	.93	1.00	-----	.98	.99	-----	.99	1.00
N,N-diethylaniline	(a)	1.00	1.01	(a)	.98	.98	.99	1.00	.99	1.00	1.03	1.01
N-isopropylaniline	.96	.96	1.01	.95	.95	.99	.96	1.00	1.01	1.01	1.04	1.01
N-butylaniline	<sup>b</sup> .91	1.00	1.03	.90	.94	1.01	.91	1.00	1.01	1.01	1.01	<sup>b</sup> 1.01
N-methyl-p-toluidine	.98	1.13	1.16	.91	1.07	1.17	1.05	1.20	1.19	1.19	1.18	1.15
N-isopropyl-p-toluidine	.89	.99	1.00	.87	.99	1.00	.88	1.01	1.03	.96	1.02	1.03
p-isopropylaniline	1.00	1.09	1.16	1.00	1.08	1.16	1.02	1.11	1.13	1.11	1.16	1.12
2,6-xylydine	.95	1.04	1.07	1.00	1.03	1.11	1.06	1.10	1.10	1.07	1.15	1.12
4-isopropyl-2-methylaniline	.86	1.10	1.11	.86	1.00	1.12	.95	1.07	1.12	1.11	1.11	1.12
o-methoxyaniline	.76	1.00	1.00	.74	.91	1.01	.80	1.01	1.03	.99	1.03	1.04
Xylidines <sup>c</sup> (commercial)	1.03	1.01	1.09	.97	1.03	1.11	1.02	1.09	1.10	1.10	1.11	1.10

<sup>a</sup>Insufficient fuel to complete performance test.

<sup>b</sup>Values obtained by extrapolation.

<sup>c</sup>Unpublished data.

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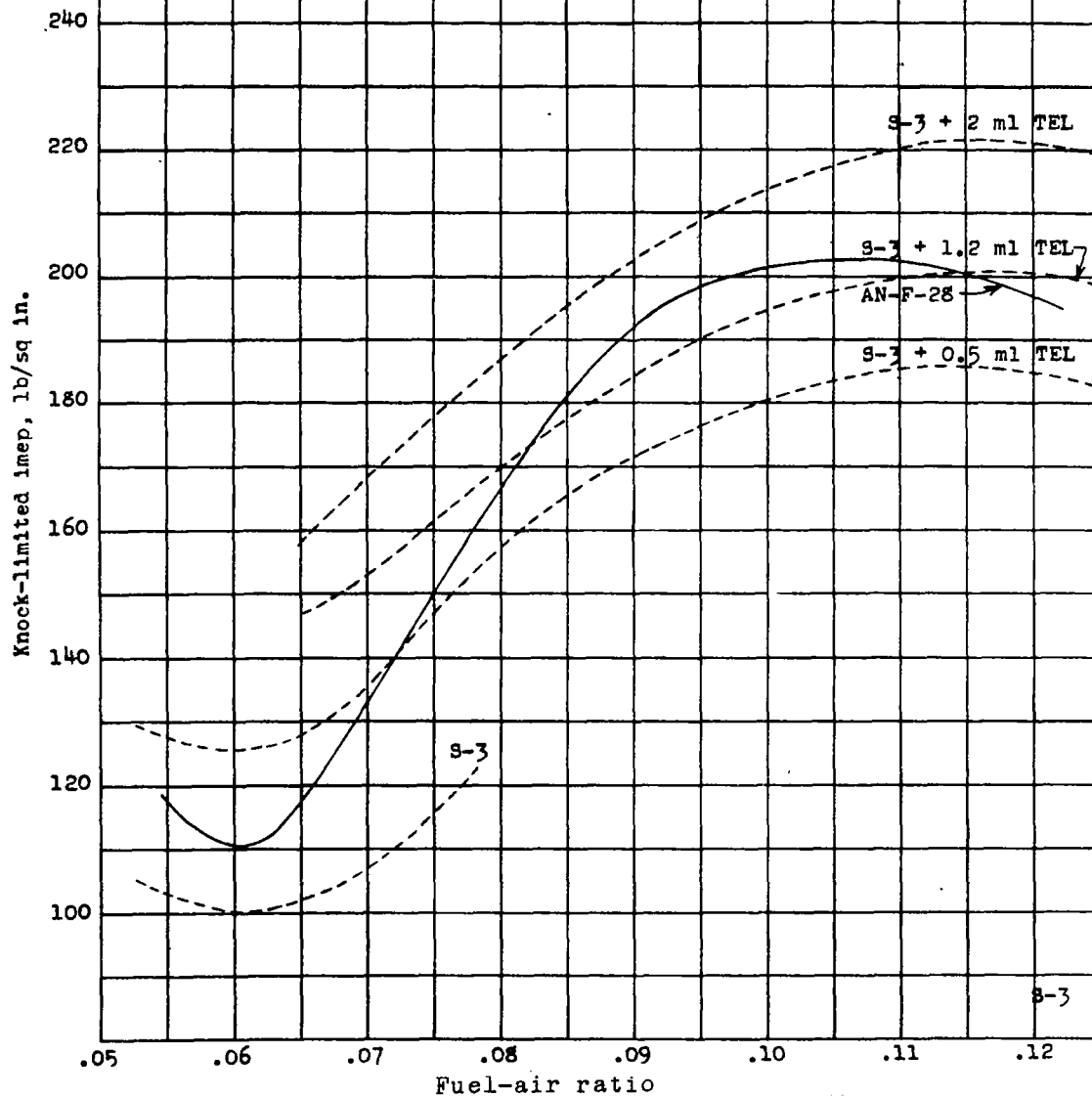
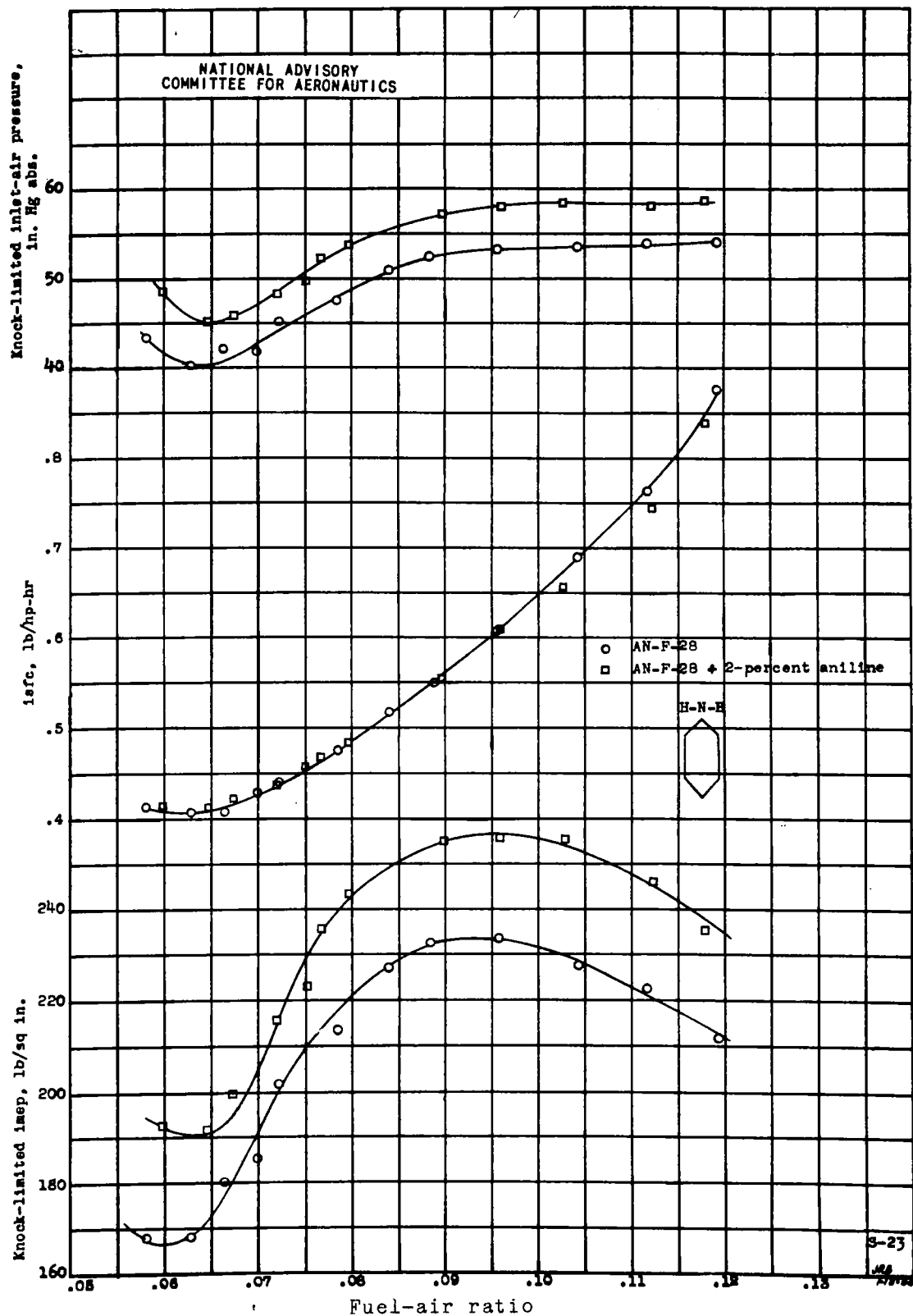


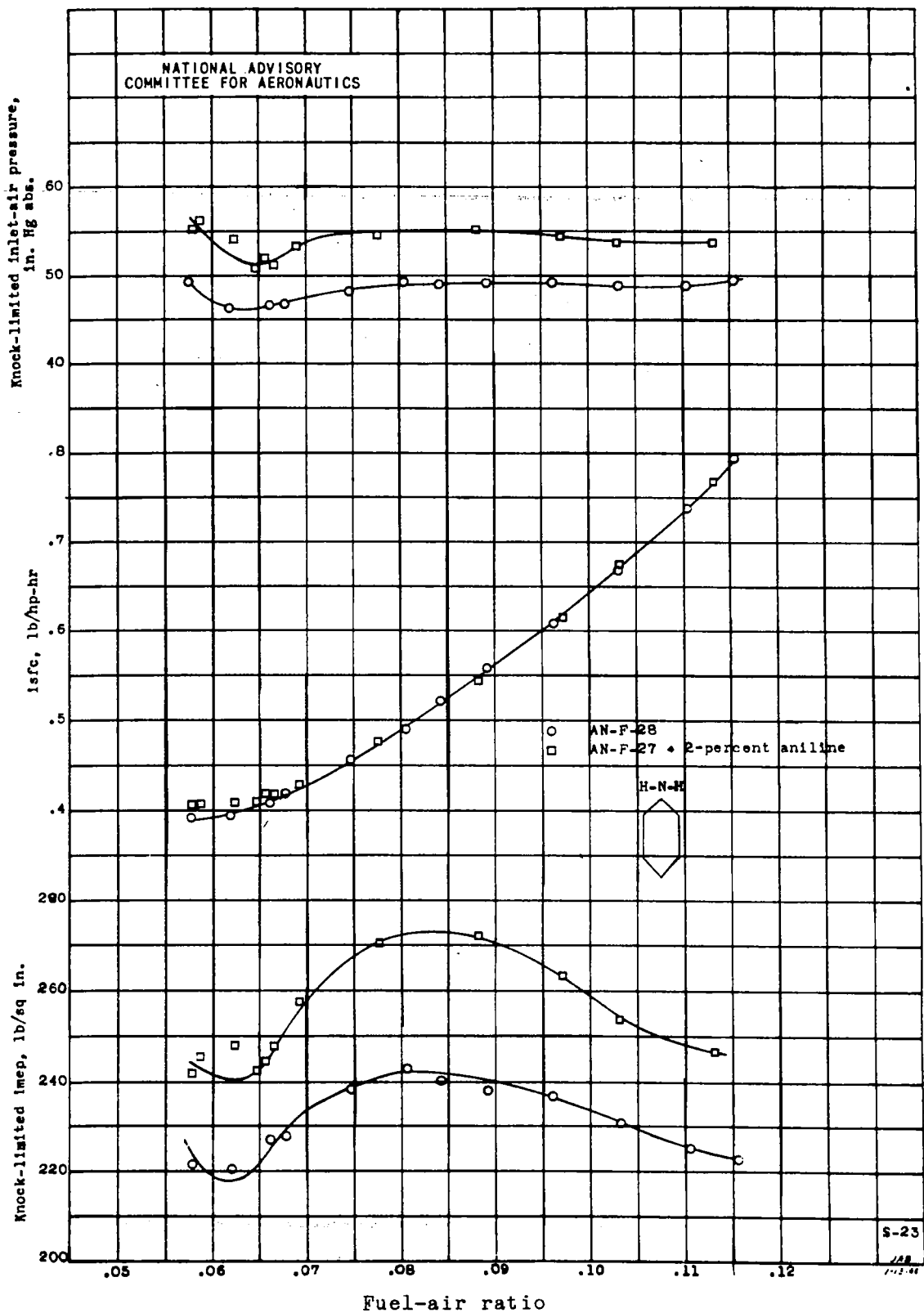
Figure 1. - Knock-limited F-4 performance of AN-F-28 fuel and corresponding S reference curves. Inlet-air temperature, 225° F; spark advance, 45° B.T.C.; coolant temperature, 375° F; engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.





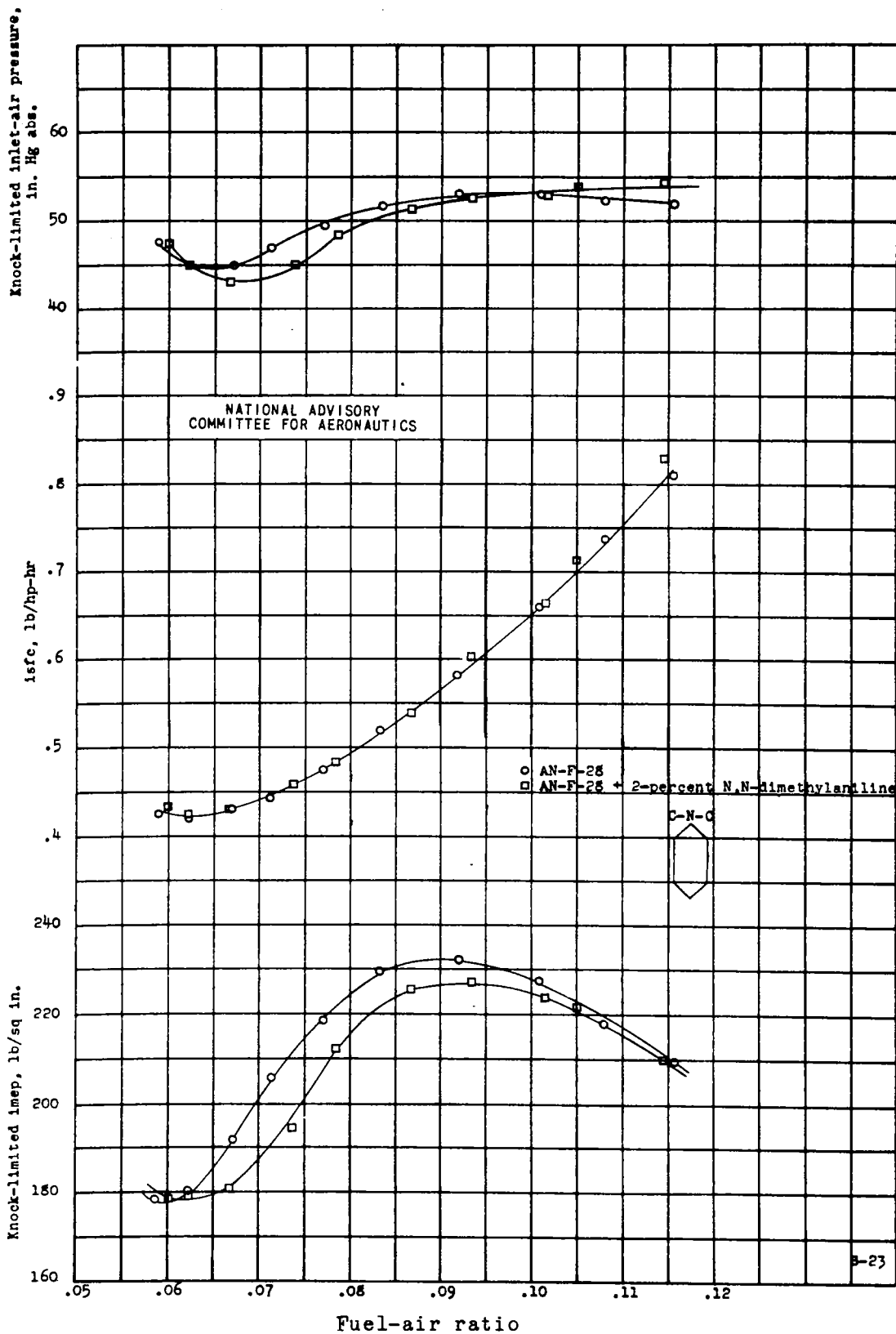
(a) Inlet-air temperature, 250° F; spark advance, 30° B.T.C.; coolant temperature, 250° F.

Figure 2. - Effect of addition of 2-percent aniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



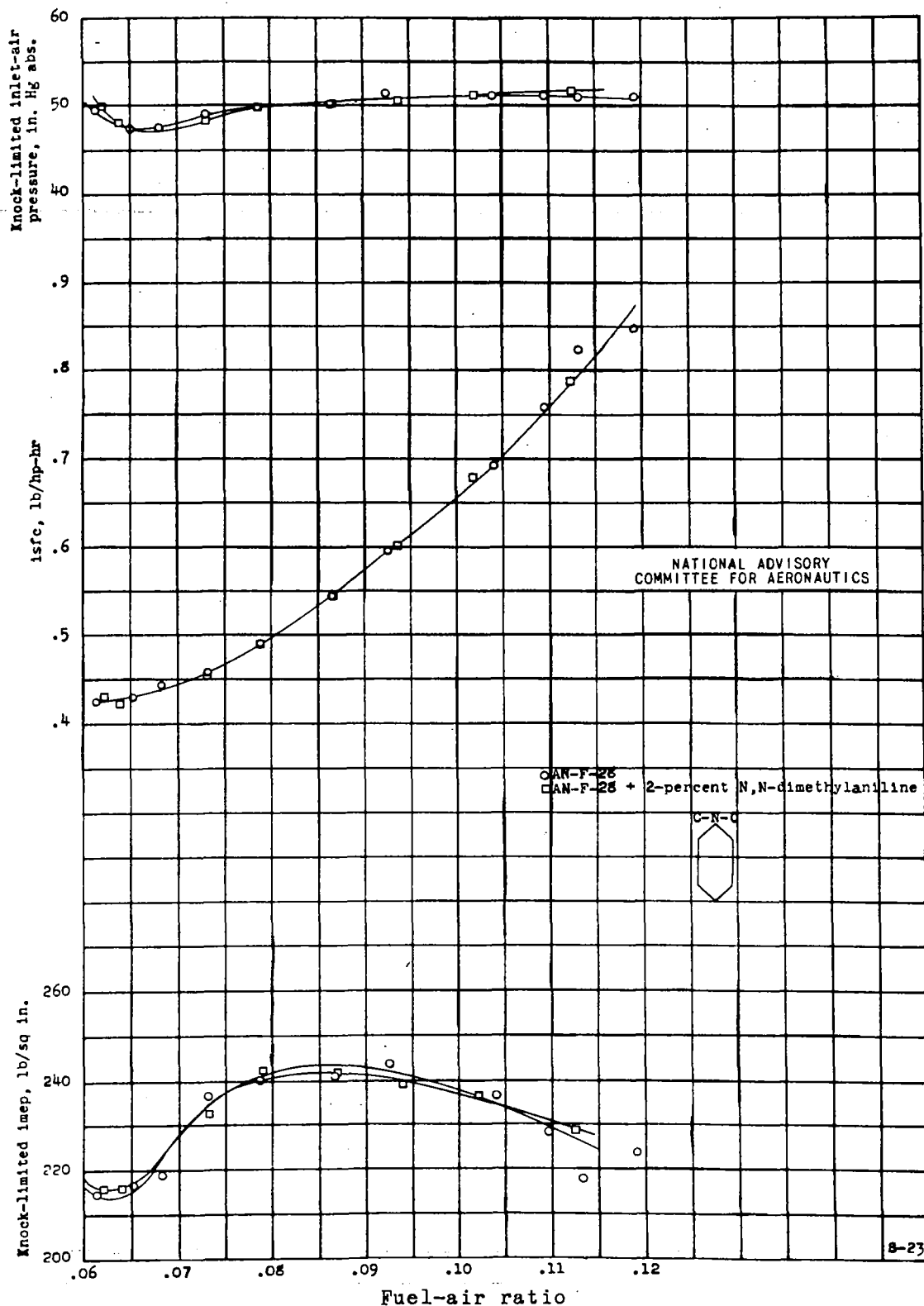
(b) Inlet-air temperature,  $150^{\circ}\text{F}$ ; spark advance,  $30^{\circ}\text{B.T.C.}$ ; coolant temperature,  $250^{\circ}\text{F}$ .

Figure 2. - Concluded. Effect of addition of 2-percent aniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature,  $165^{\circ}\text{F}$ .



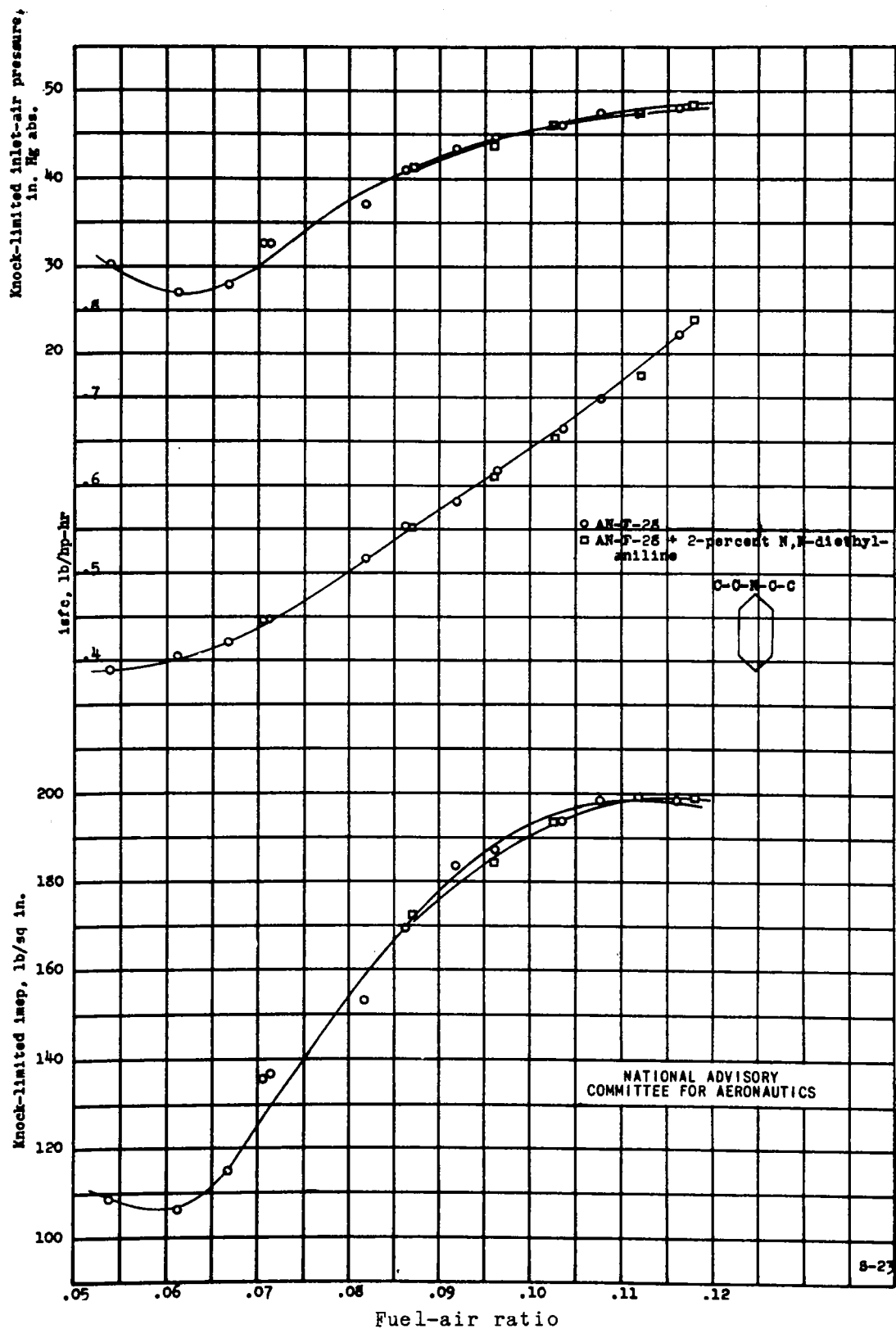
(a) Inlet-air temperature, 250° F; spark advance, 30° B.T.C.; coolant temperature, 250° F.

Figure 3. - Effect of addition of 2-percent N, N-dimethylaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



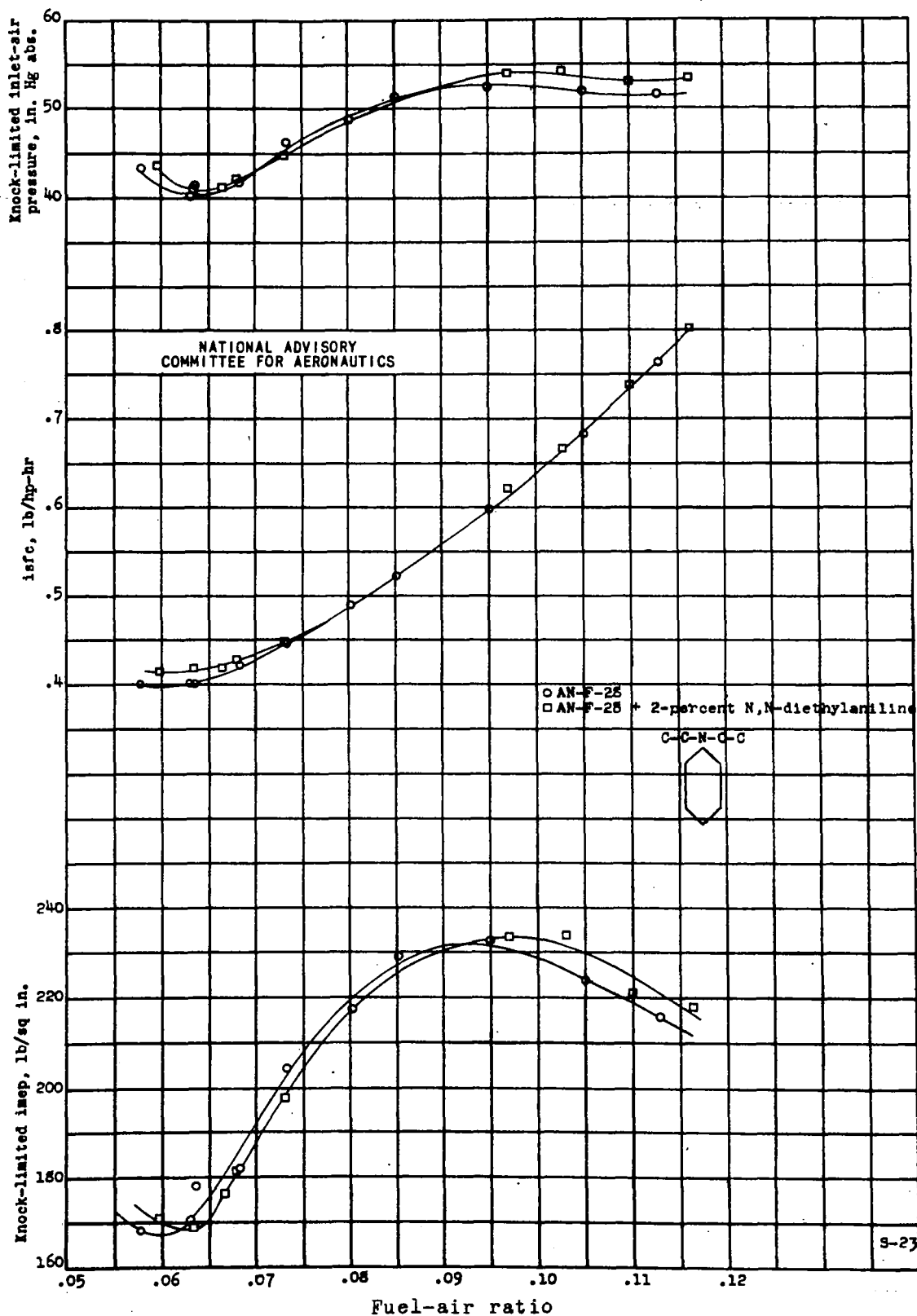
(b) Inlet-air temperature, 150° F; spark advance, 30° B.T.C.; coolant temperature, 250° F.

Figure 3. - Concluded. Effect of addition of 2-percent N, N-dimethylaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



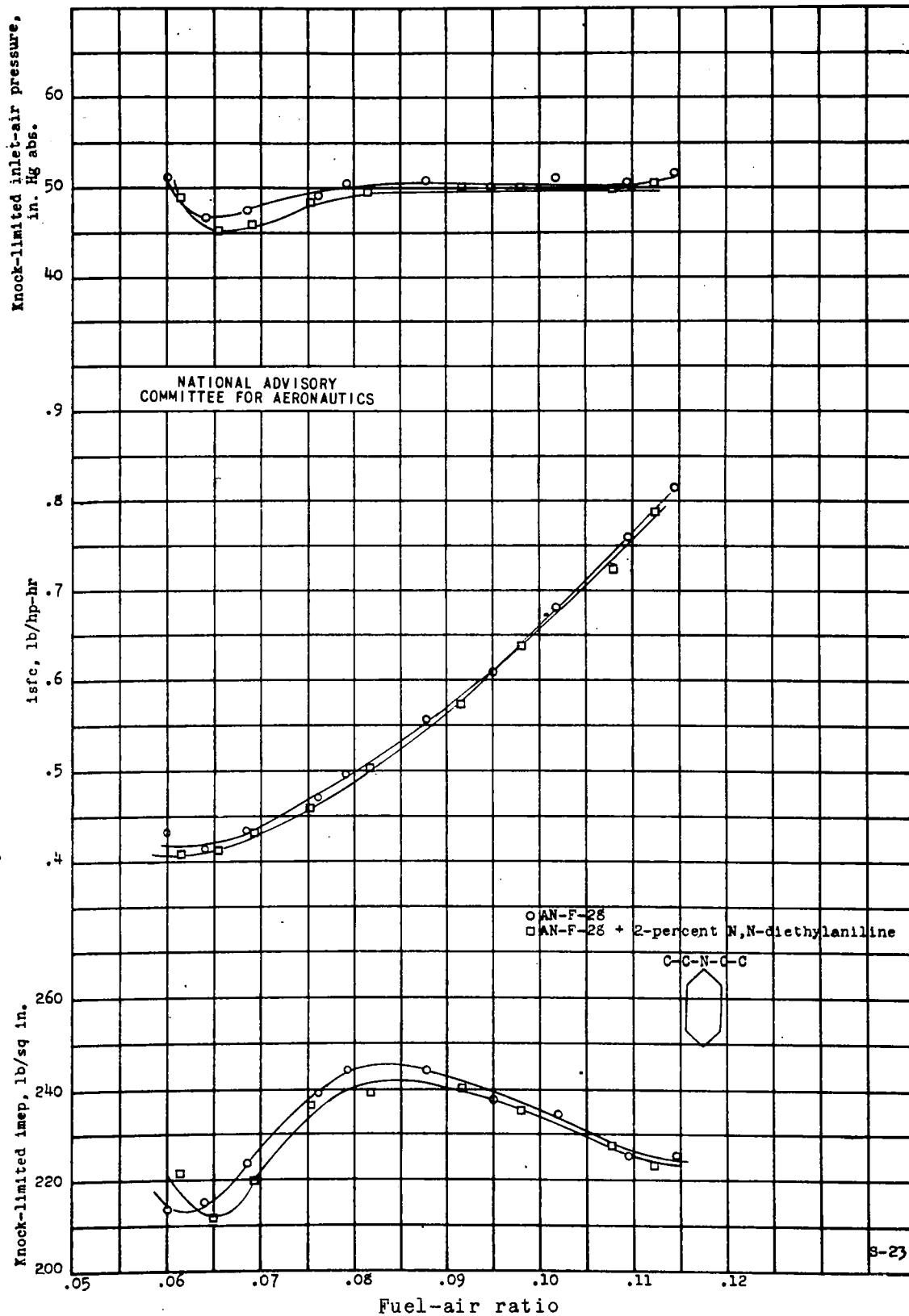
(a) Inlet-air temperature, 225° F; spark advance, 45° B.T.C.; coolant temperature, 375° F.

Figure 4. - Effect of addition of 2-percent N, N-diethylaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



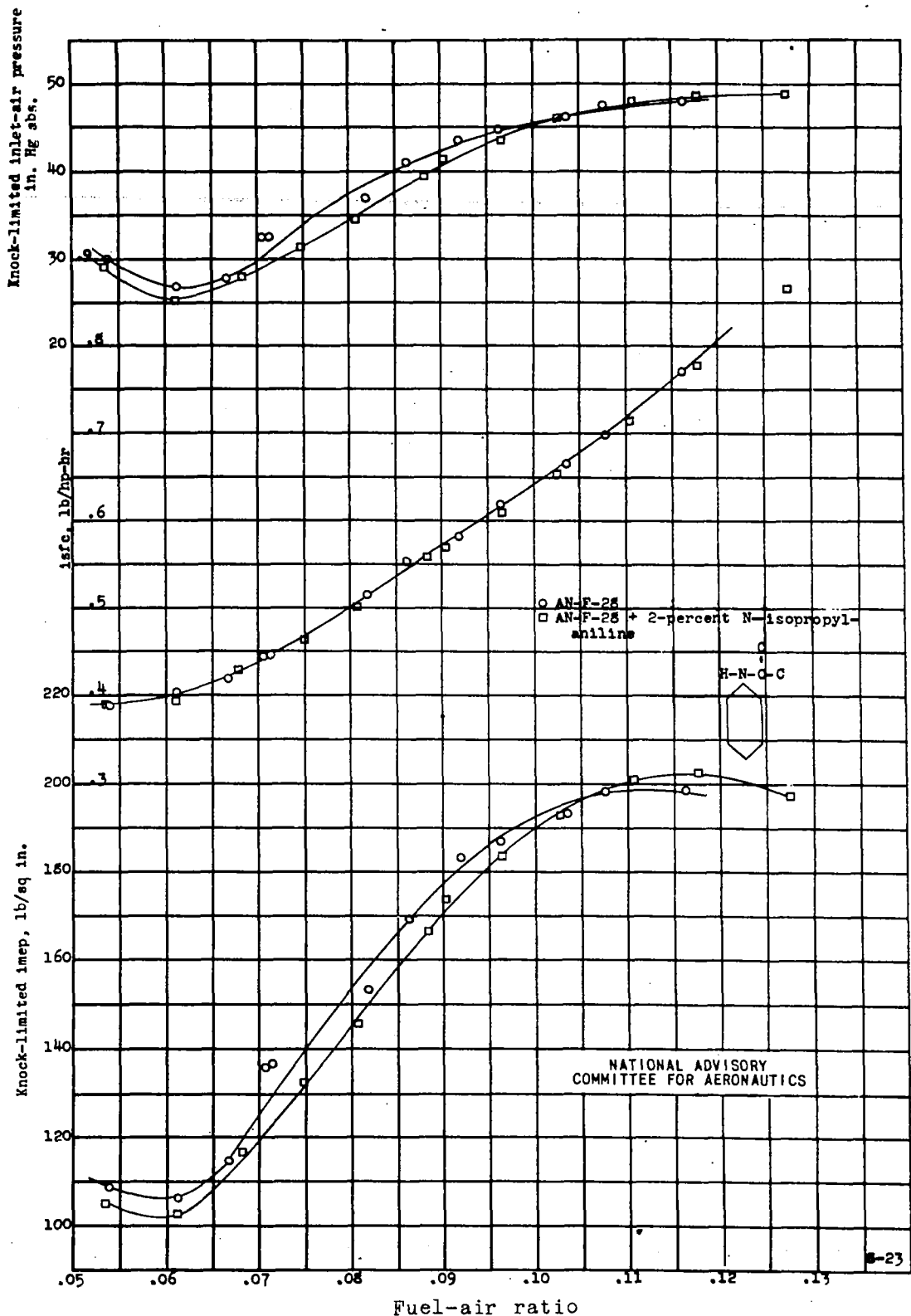
(b) Inlet-air temperature, 250° F; spark advance, 30° B.T.C.; coolant temperature, 250° F.

Figure 4. - Continued. Effect of addition of 2-percent N, N-diethylaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



(c) Inlet-air temperature, 150° F; spark advance, 30° B.T.C.; coolant temperature, 250° F.

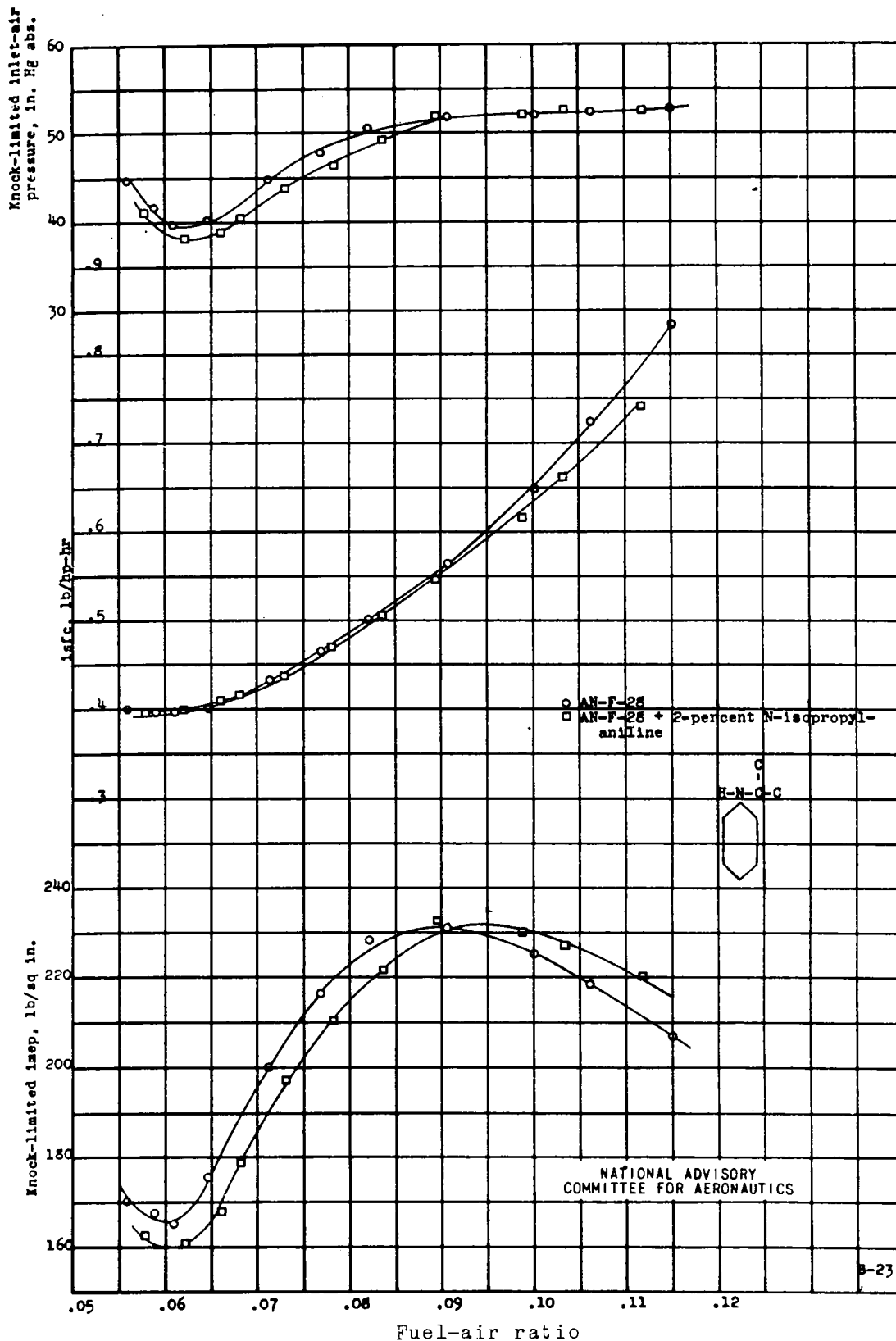
Figure 4. - Concluded. Effect of addition of 2-percent N, N-diethylaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



(a) Inlet-air temperature, 225° F; spark advance, 45° B.T.C.; coolant temperature, 375° F.

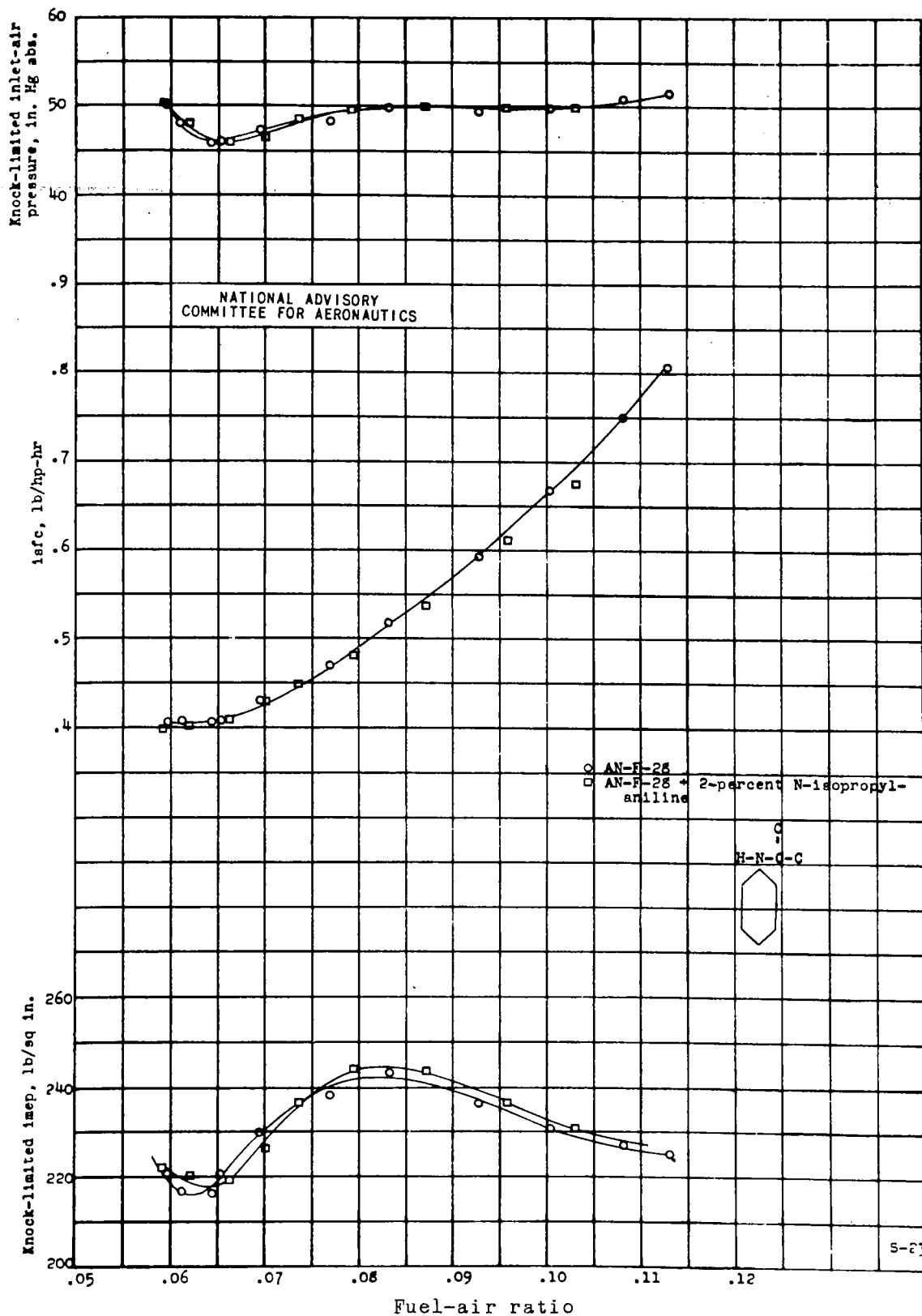
Figure 5. - Effect of addition of 2-percent N-isopropylaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.





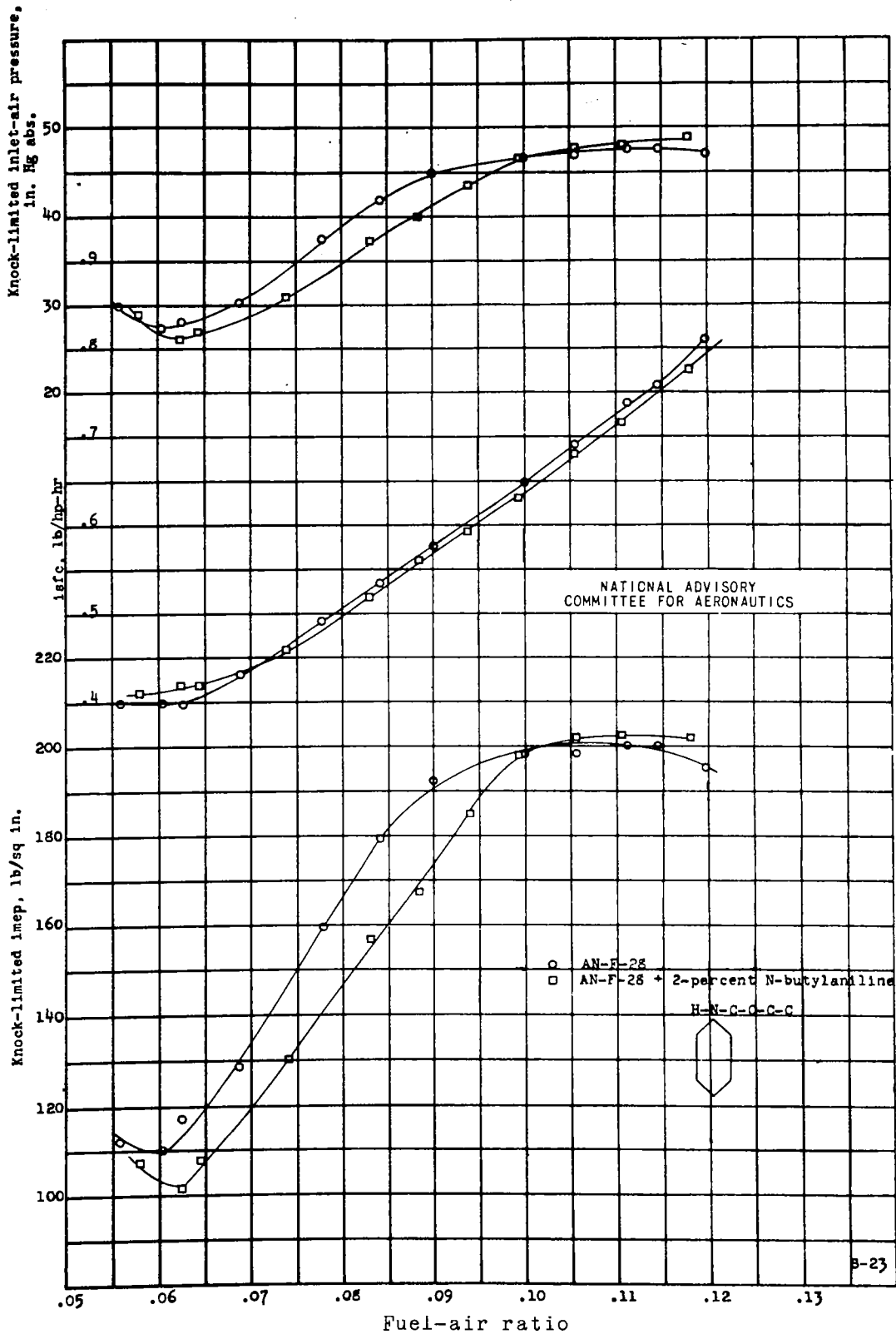
(b) Inlet-air temperature, 250° F; spark advance, 30° B.T.C.; coolant temperature, 250° F.

Figure 5. - Continued. Effect of addition of 2-percent N-isopropylaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



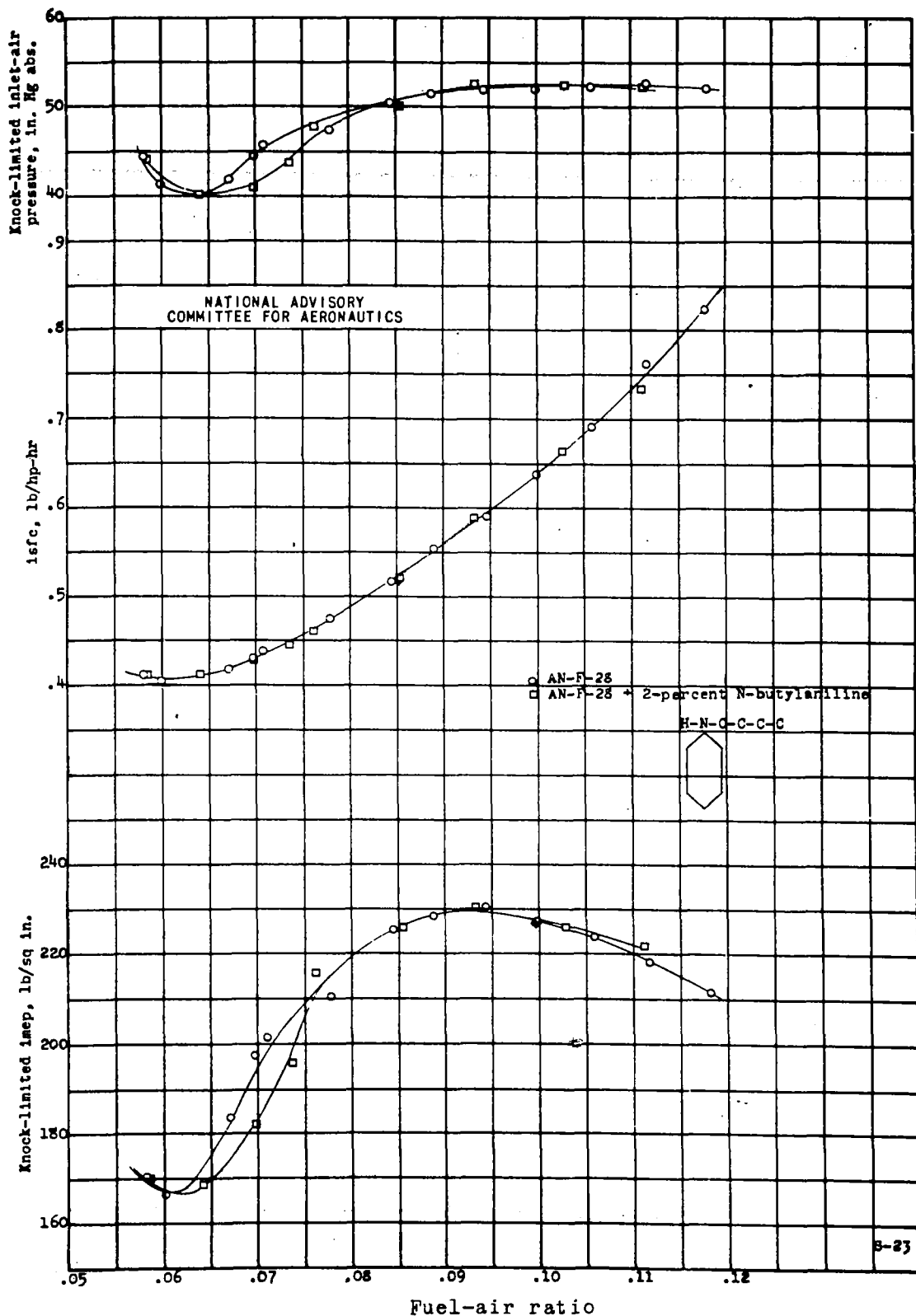
(c) Inlet-air temperature, 150° F; spark advance, 30° B.T.C.; coolant temperature, 250° F.

Figure 5. - Concluded. Effect of addition of 2-percent N-isopropylaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



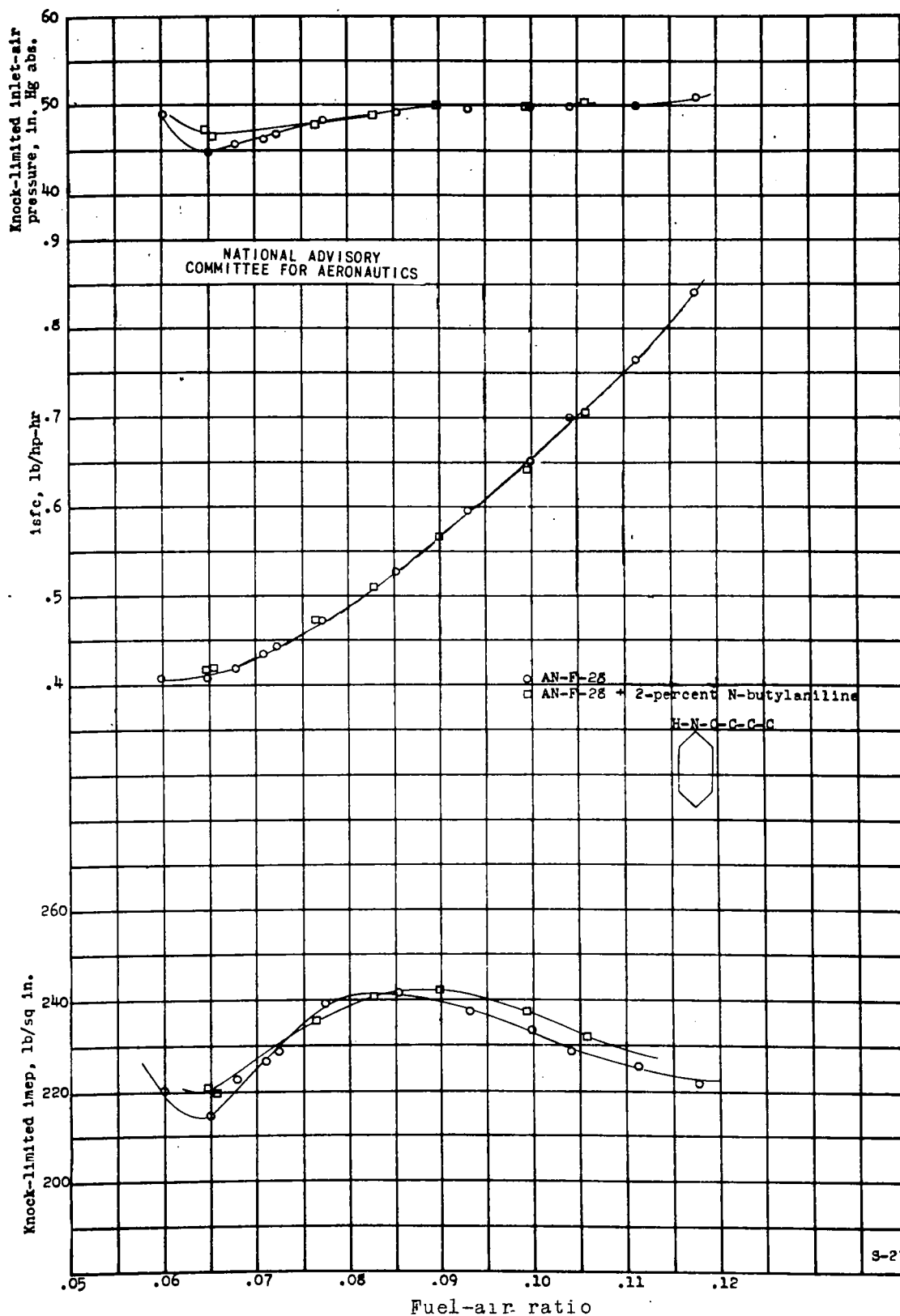
(a) Inlet-air temperature, 225° F; spark advance, 45° B.T.C.; coolant temperature, 375° F.

Figure 6. - Effect of addition of 2-percent N-butylaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



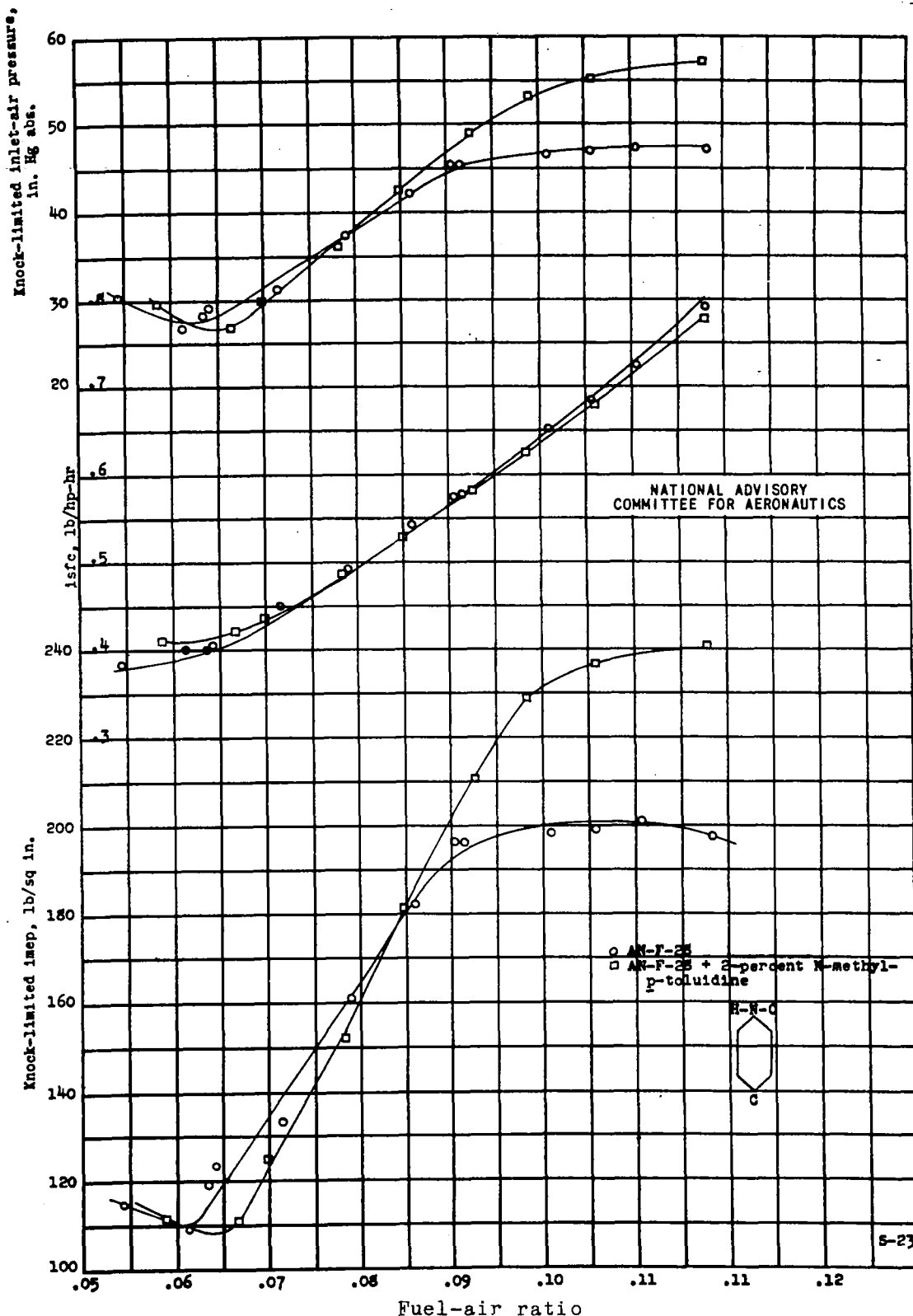
(b) Inlet-air temperature, 250° F; spark advance, 30° B.T.C.; coolant temperature, 250° F.

Figure 6. - Continued. Effect of addition of 2-percent N-butylaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



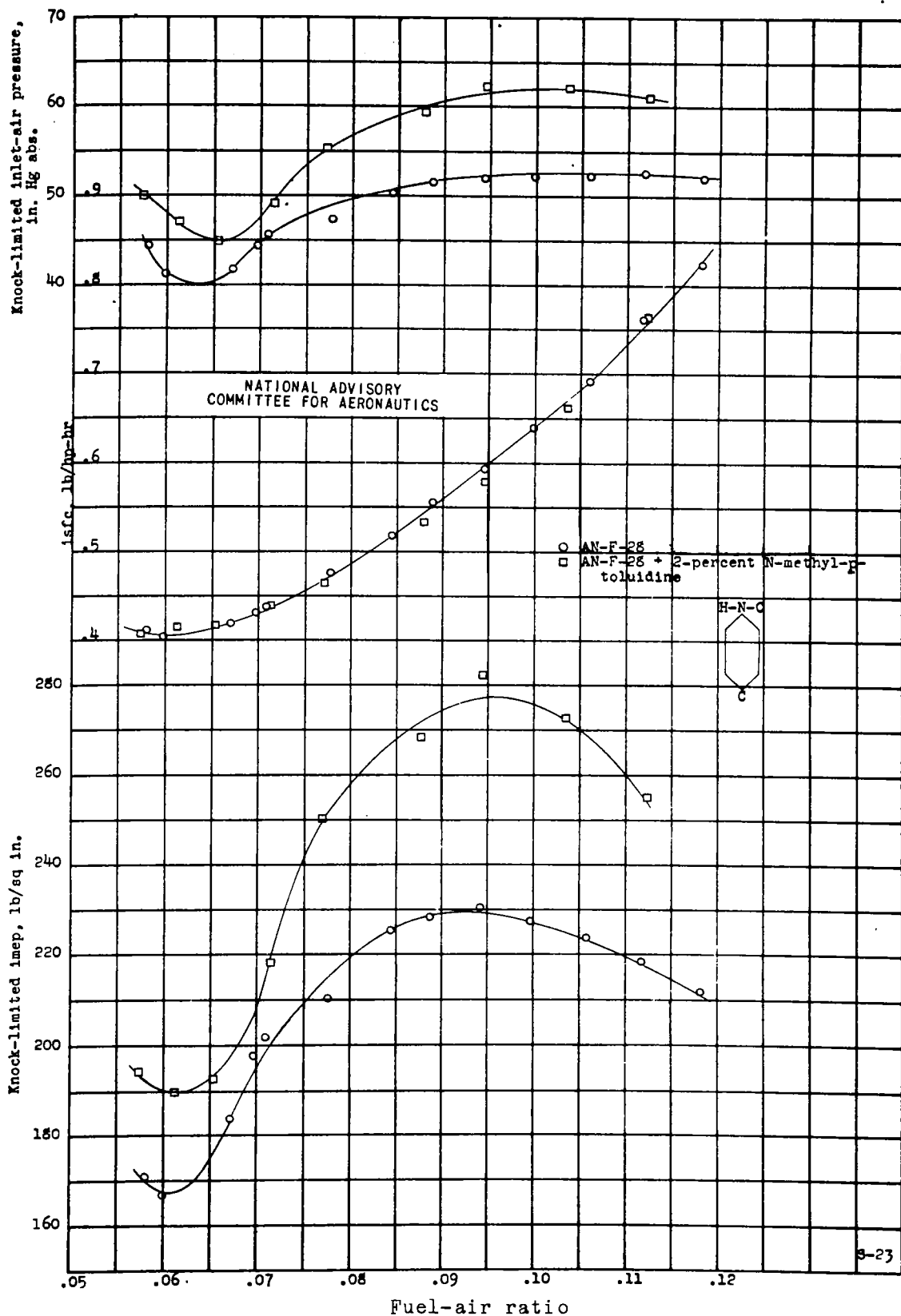
(c) Inlet-air temperature,  $150^{\circ}\text{F}$ ; spark advance,  $30^{\circ}\text{B.T.C.}$ ; coolant temperature,  $250^{\circ}\text{F}$ .

Figure 6. - Concluded. Effect of addition of 2-percent N-butylaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature,  $165^{\circ}\text{F}$ .



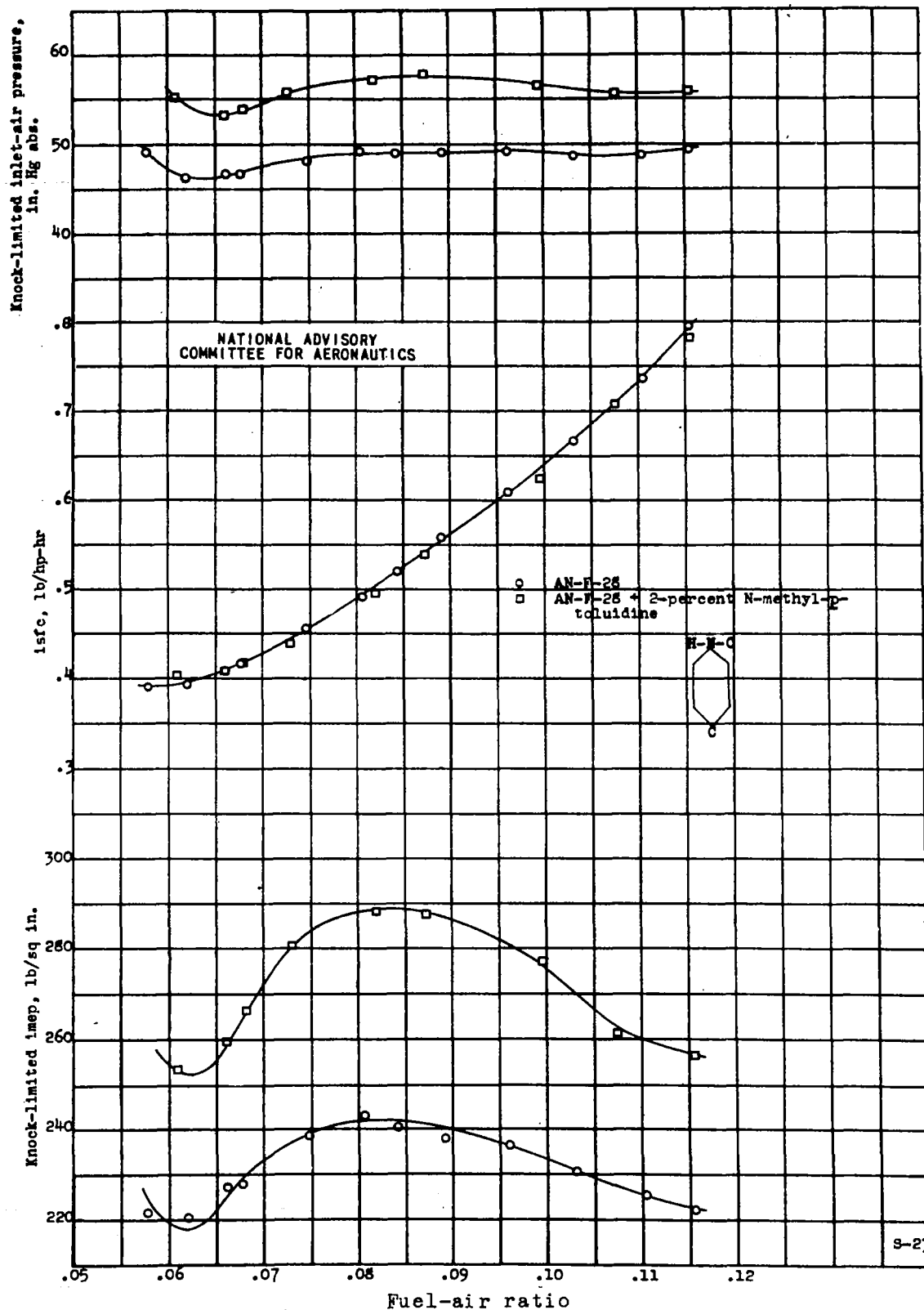
(a) Inlet-air temperature, 225° F; spark advance, 45° B.T.C.; coolant temperature, 375° F.

Figure 7. - Effect of addition of 2-percent N-methyl-p-toluidine to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



(b) Inlet-air temperature,  $250^{\circ}\text{F}$ ; spark advance,  $30^{\circ}\text{B.T.C.}$ ; coolant temperature,  $250^{\circ}\text{F}$ .

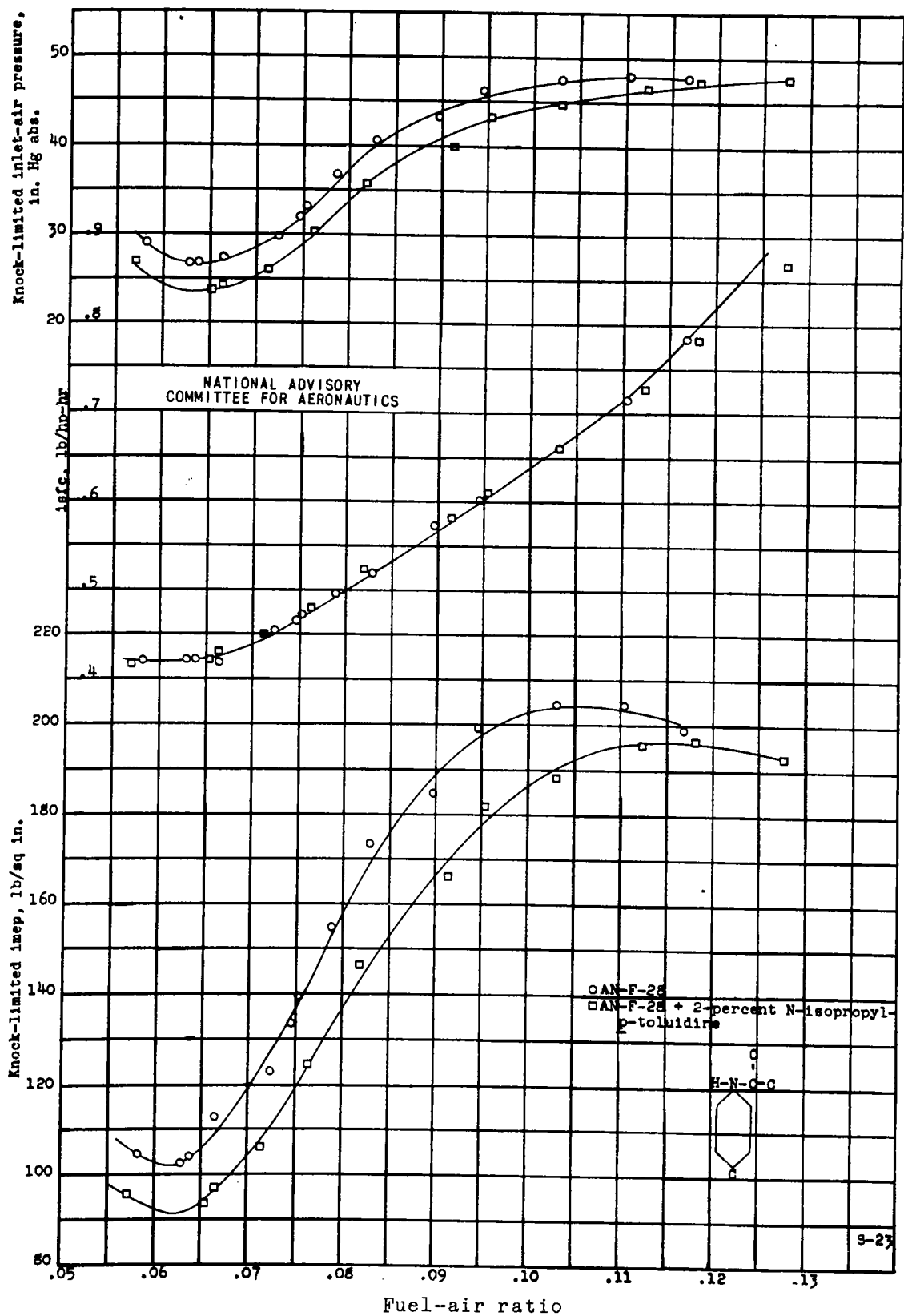
Figure 7. - Continued. Effect of addition of 2-percent N-methyl-p-toluidine to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature,  $165^{\circ}\text{F}$ .



(c) Inlet-air temperature, 150° F; spark advance, 30° B.T.C.; coolant temperature, 250° F.

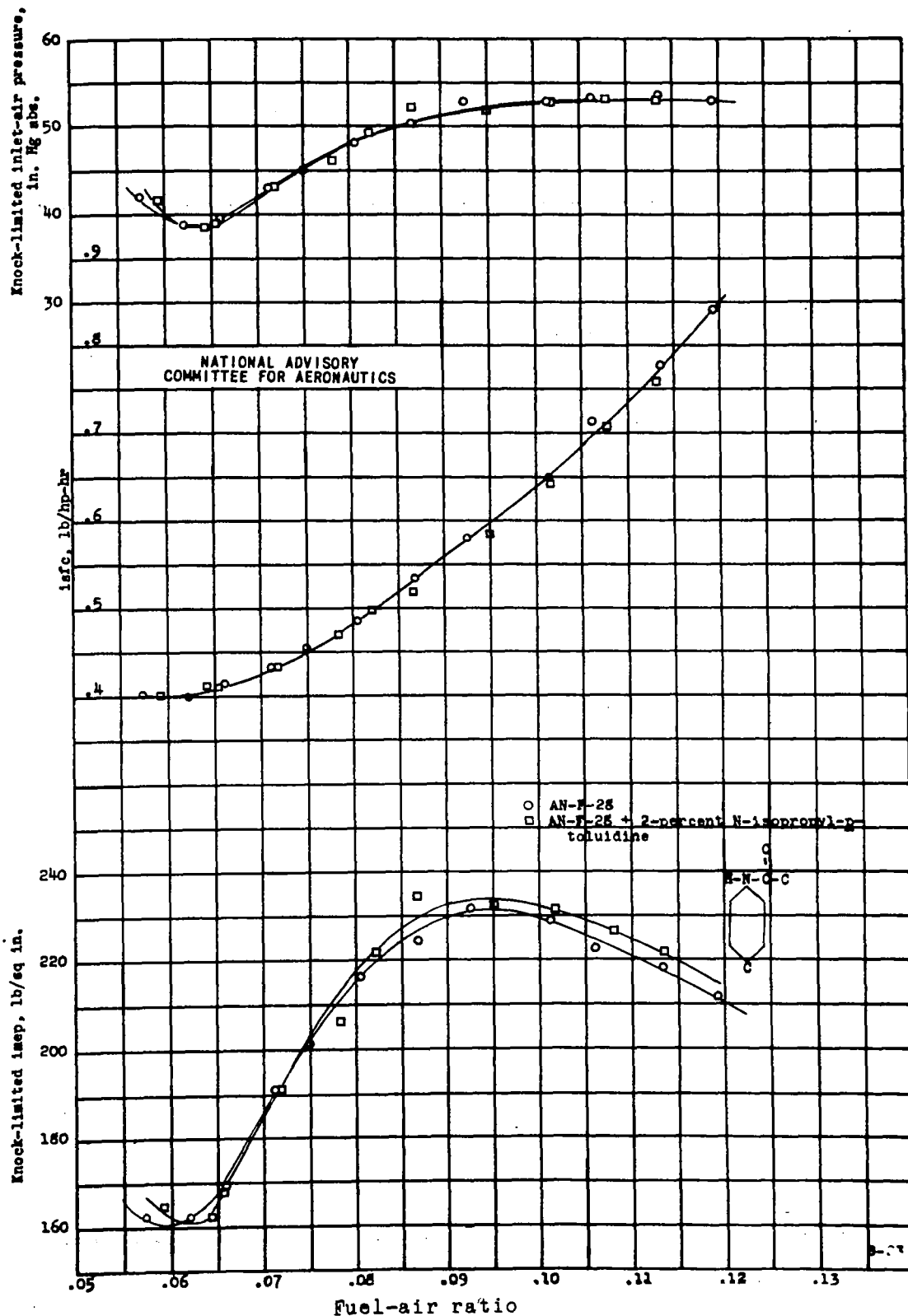
Figure 7. - Concluded. Effect of addition of 2-percent N-methyl-p-toluidine to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.





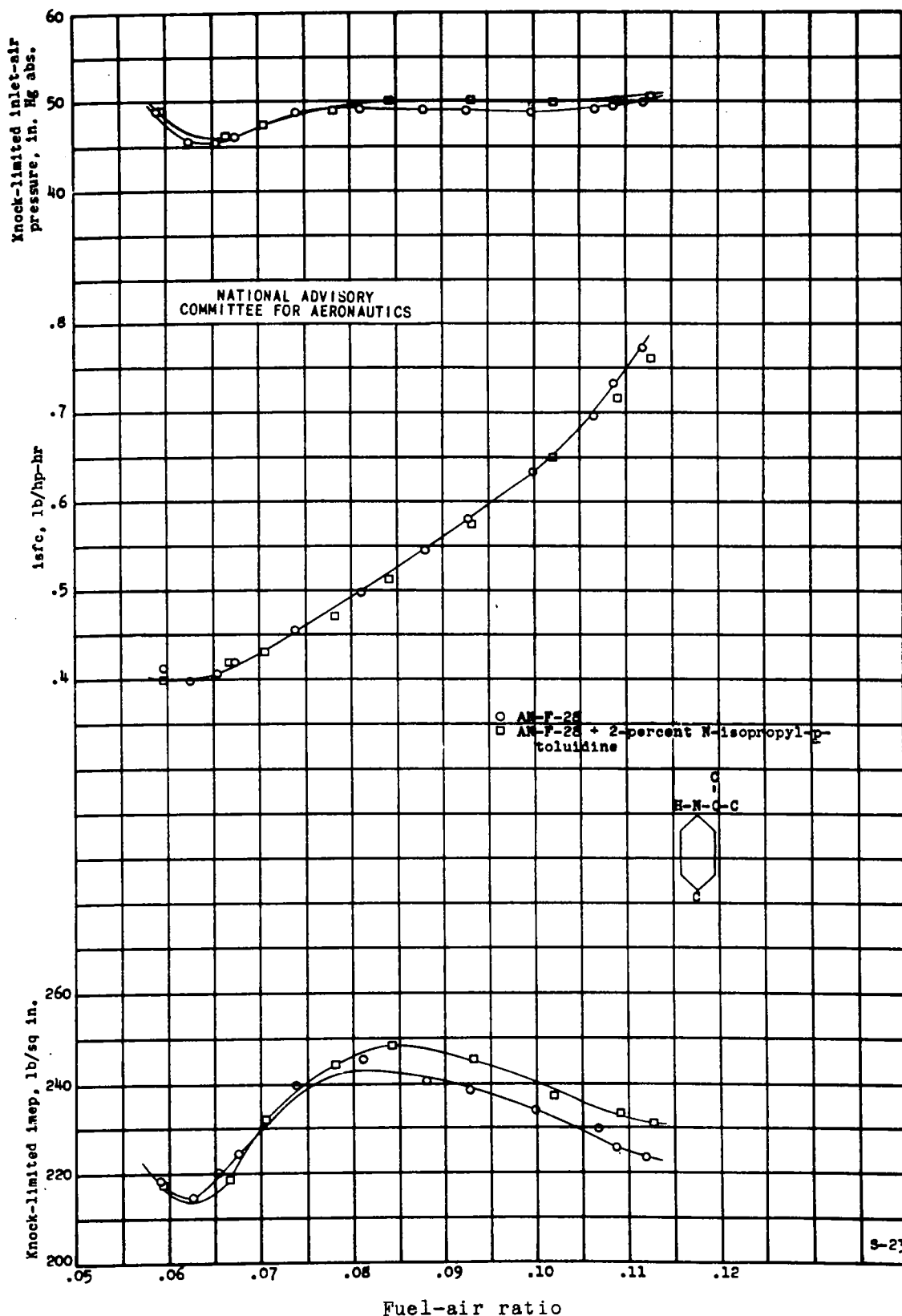
(a) Inlet-air temperature, 225° F; spark advance, 45° B.T.C.; coolant temperature, 375° F.

Figure 8. - Effect of addition of 2-percent N-isopropyl-p-toluidine to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



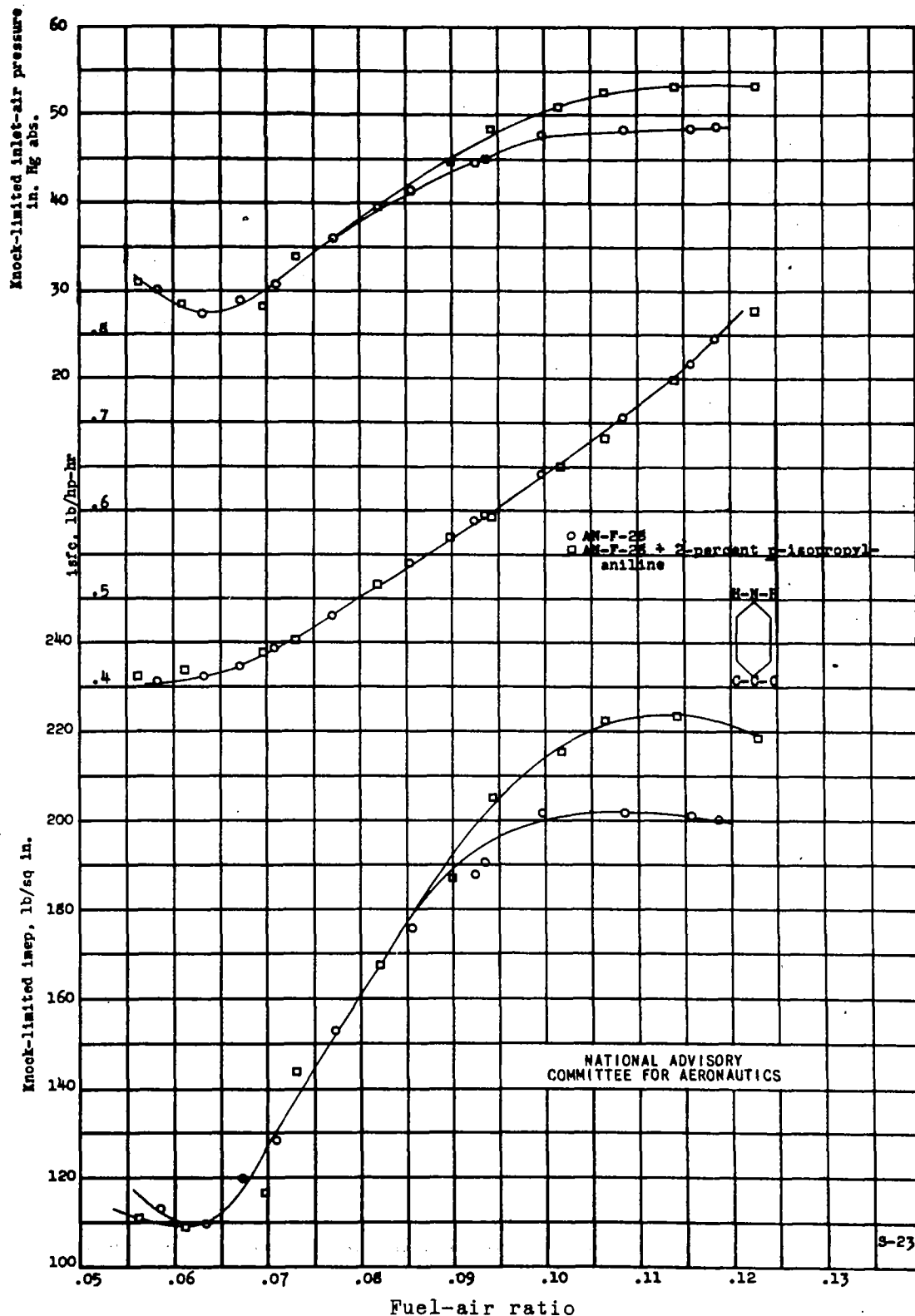
(b) Inlet-air temperature, 250° F; spark advance, 30° B.T.C.; coolant temperature, 250° F.

Figure 8. - Continued. Effect of addition of 2-percent N-isopropyl-p-toluidine to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



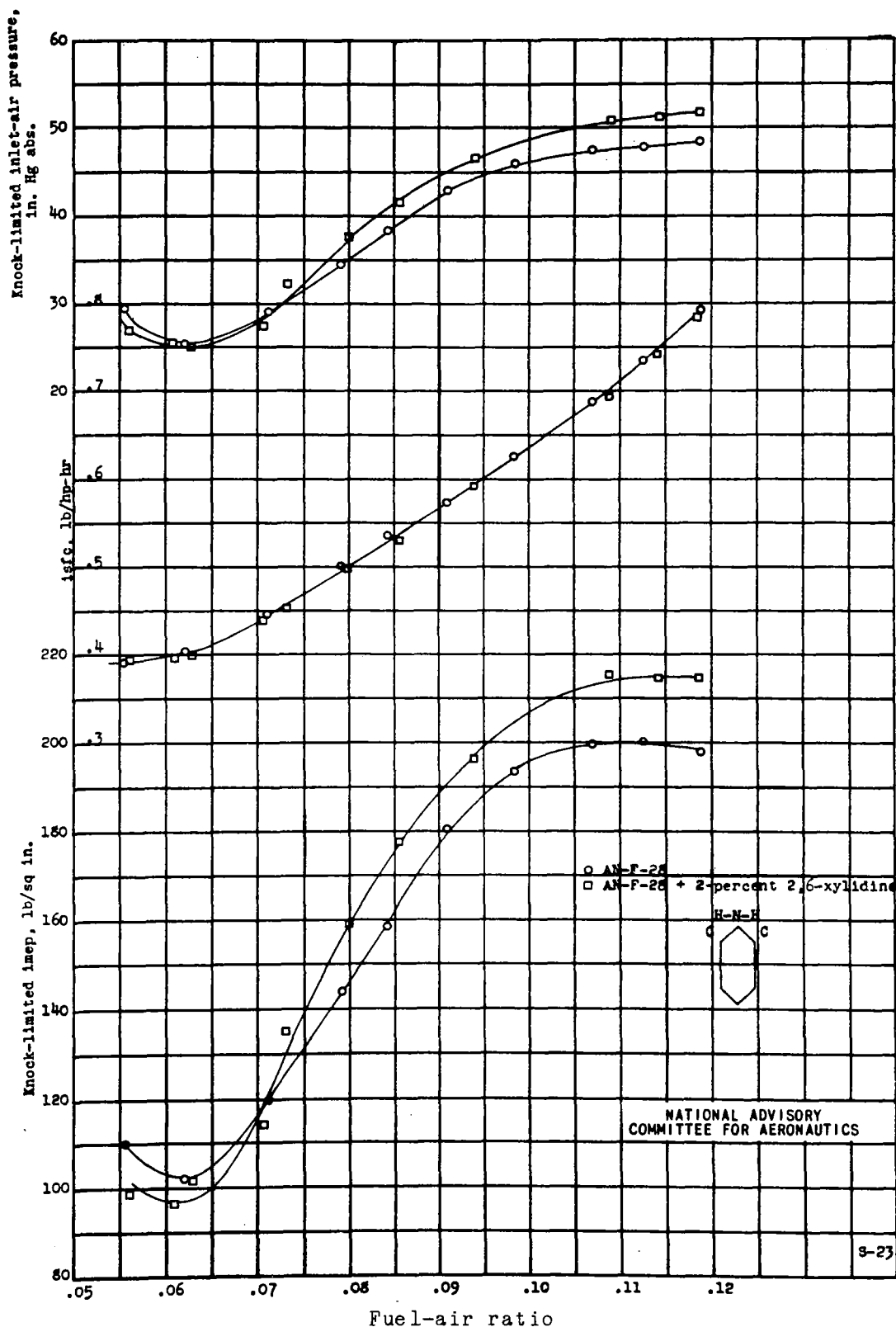
(c) Inlet-air temperature, 150° F; spark advance, 30° B.T.C.; coolant temperature, 250° F.

Figure 8. - Concluded. Effect of addition of 2-percent N-isopropyl-p-toluidine to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



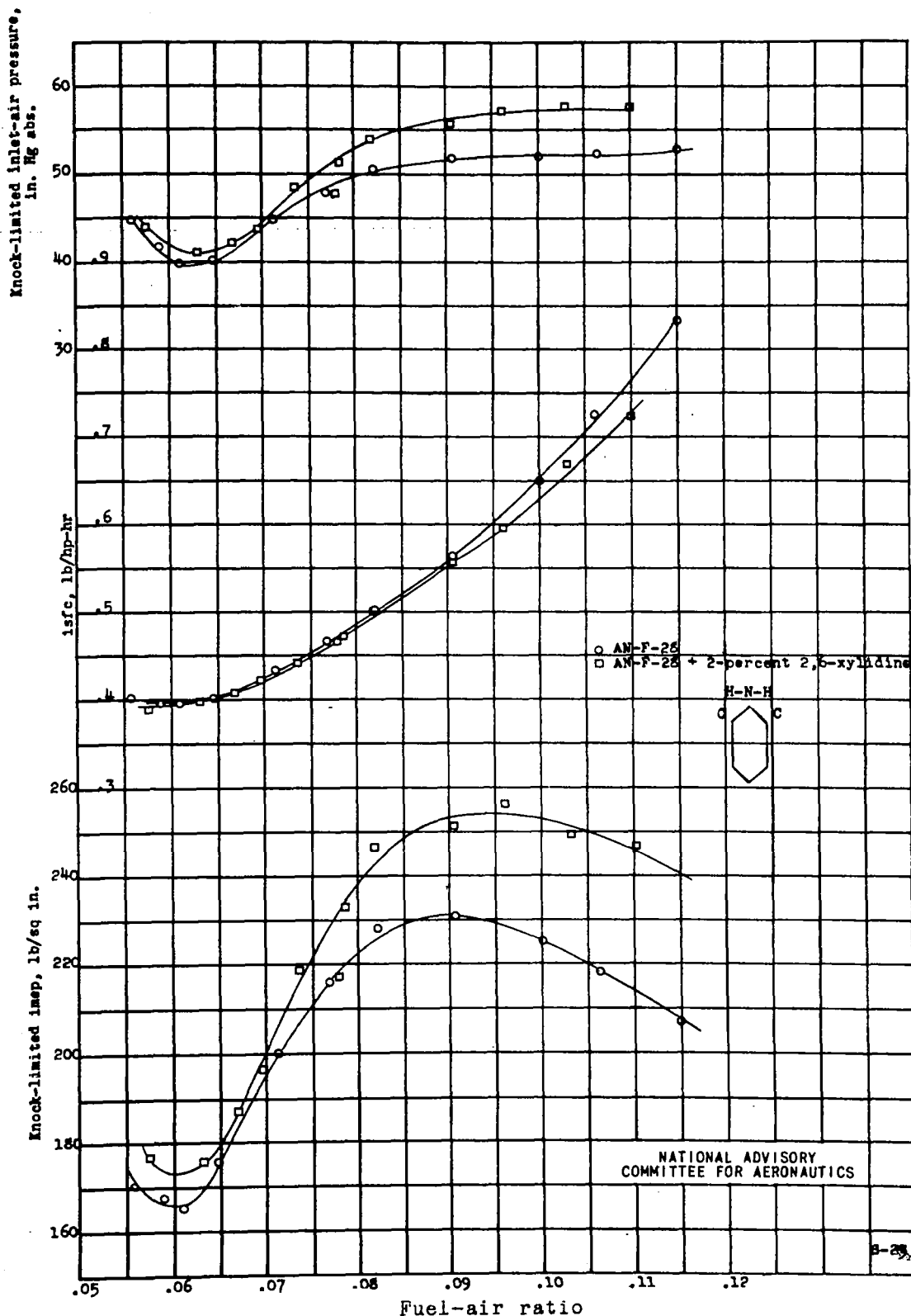
(a) Inlet-air temperature, 225° F; spark advance, 45° B.T.C.; coolant temperature, 375° F.

Figure 9. - Effect of addition of 2-percent p-isopropylaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



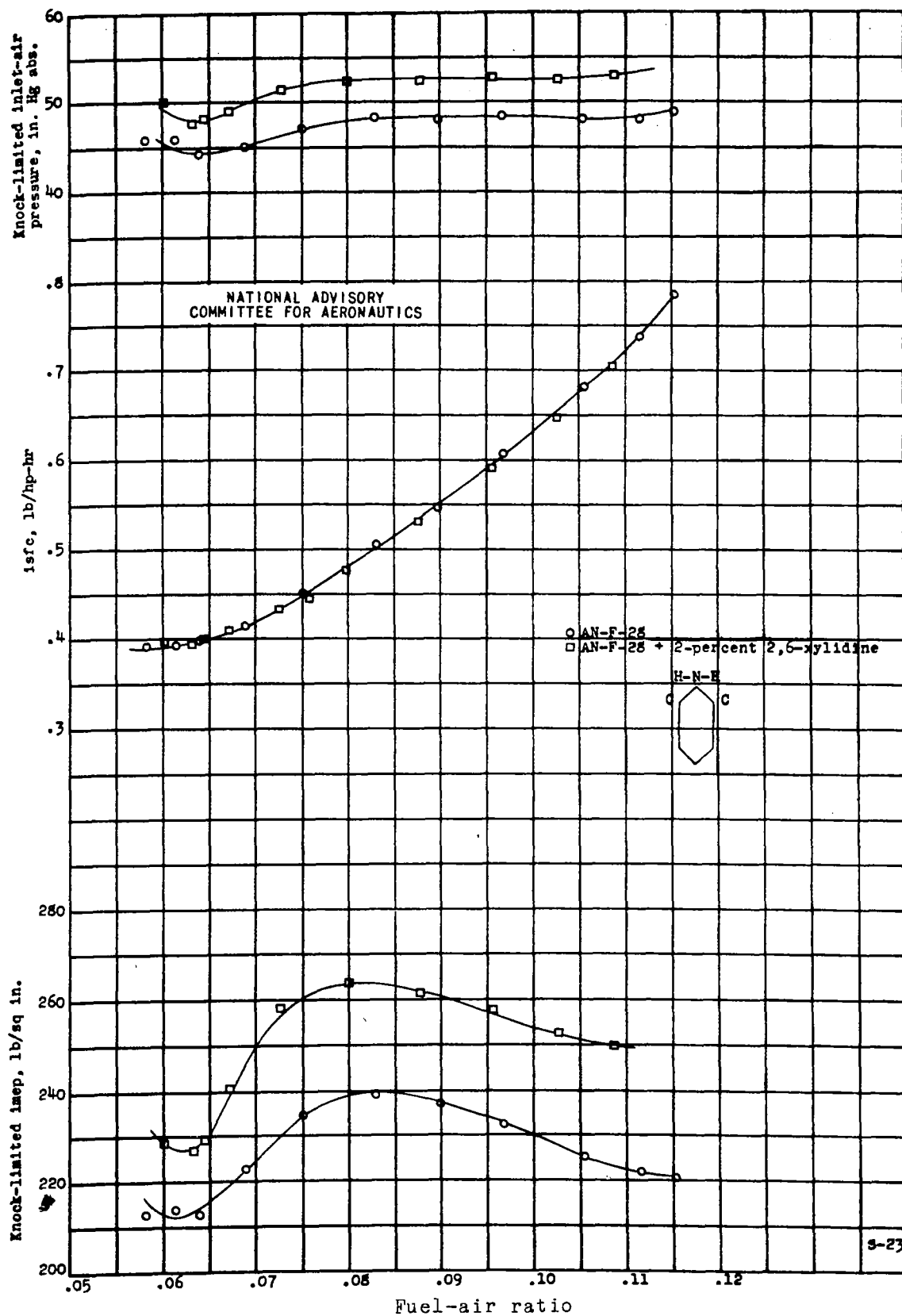
(a) Inlet-air temperature, 225° F; spark advance, 45° B.T.C.; coolant temperature, 375° F.

Figure 10. - Effect of addition of 2-percent 2, 6-xylydine to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



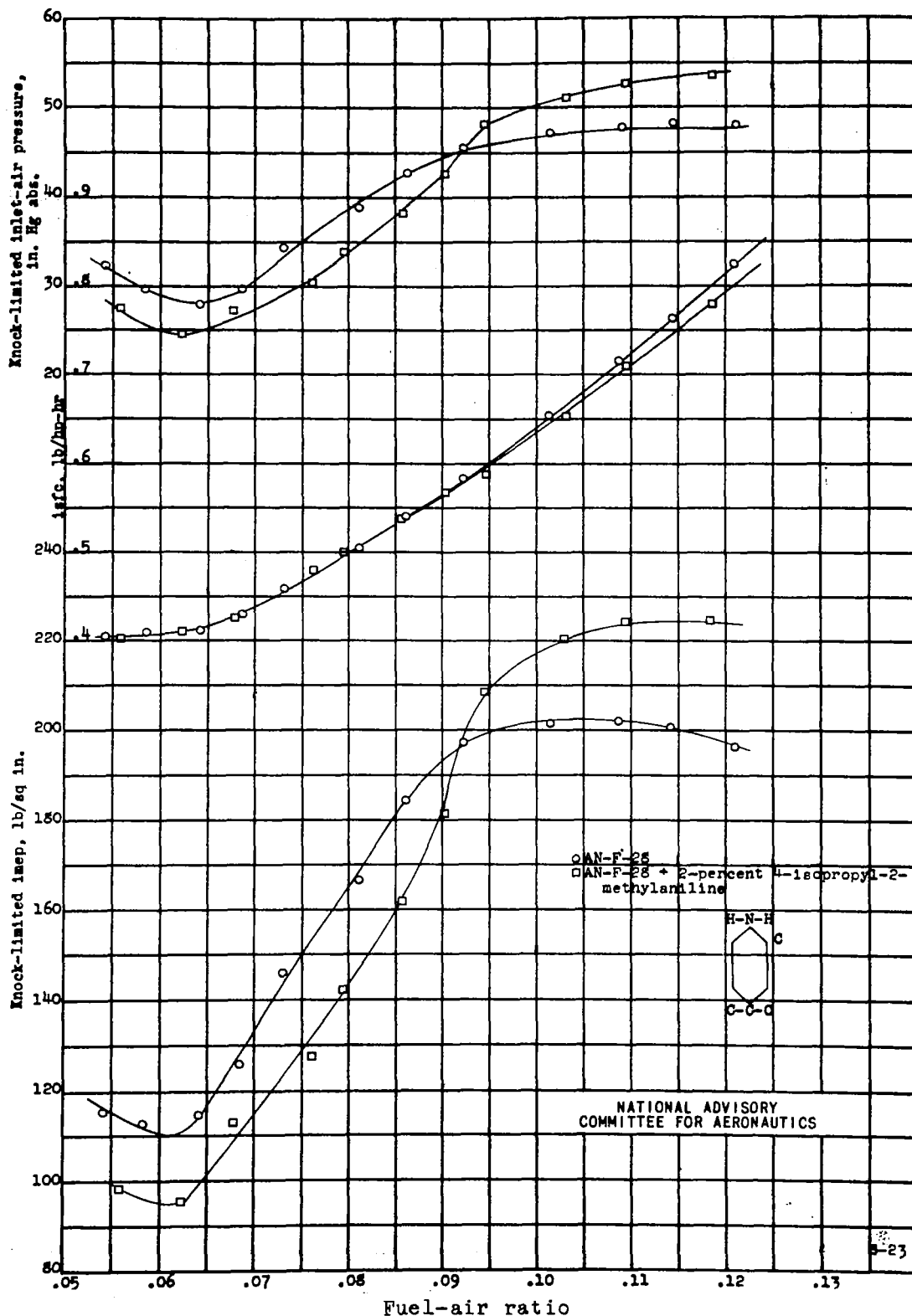
(b) Inlet-air temperature, 250° F; spark advance, 30° B.T.C.; coolant temperature, 250° F.

Figure 10. - Continued. Effect of addition of 2-percent 2, 6-xylydine to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



(c) Inlet-air temperature, 150° F; spark advance, 30° B.T.C.; coolant temperature, 250° F.

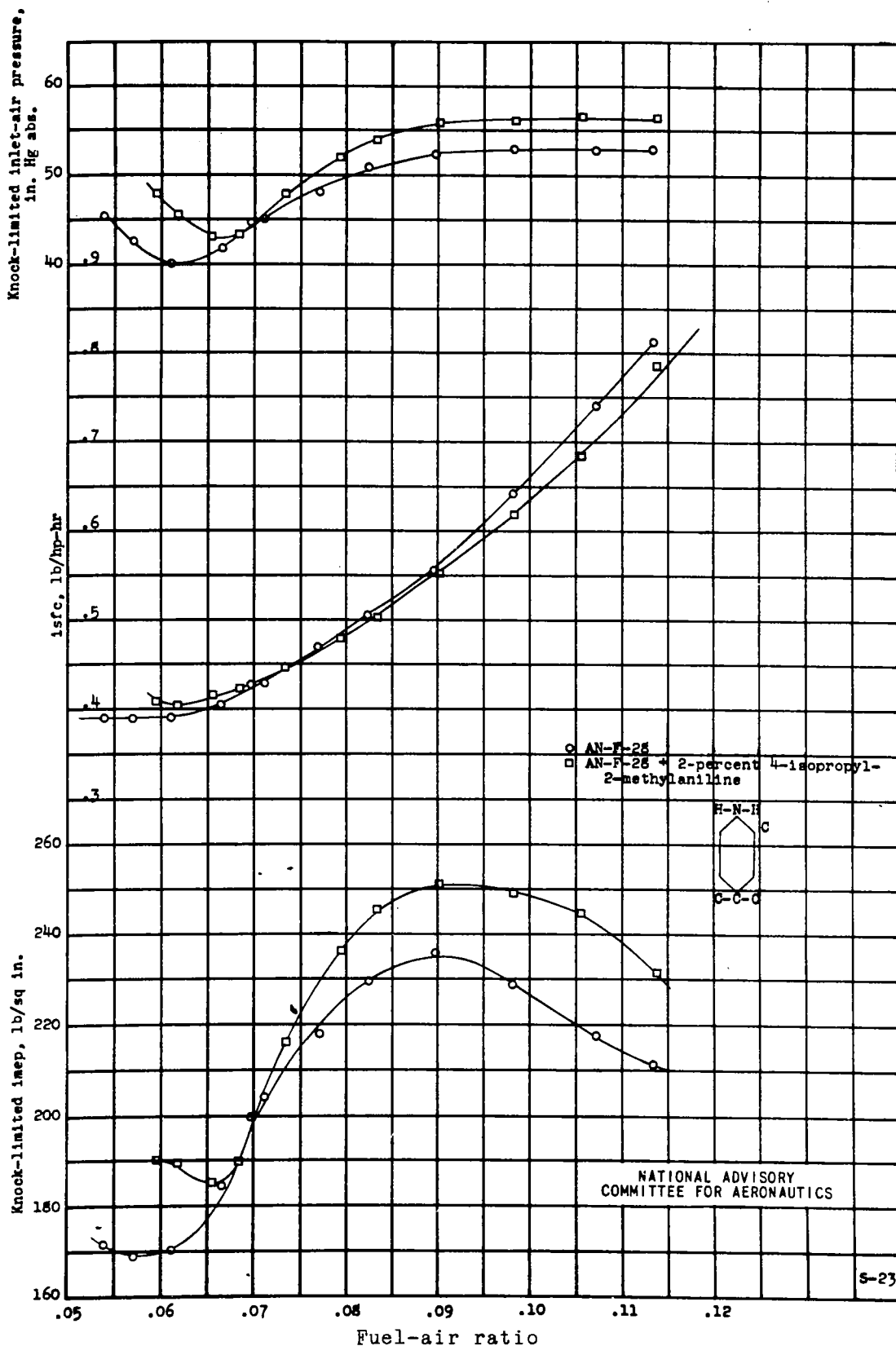
Figure 10. - Concluded. Effect of addition of 2-percent 2, 6-xylydine to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



(a) Inlet-air temperature, 225° F; spark advance, 45° B.T.C.; coolant temperature, 375° F.

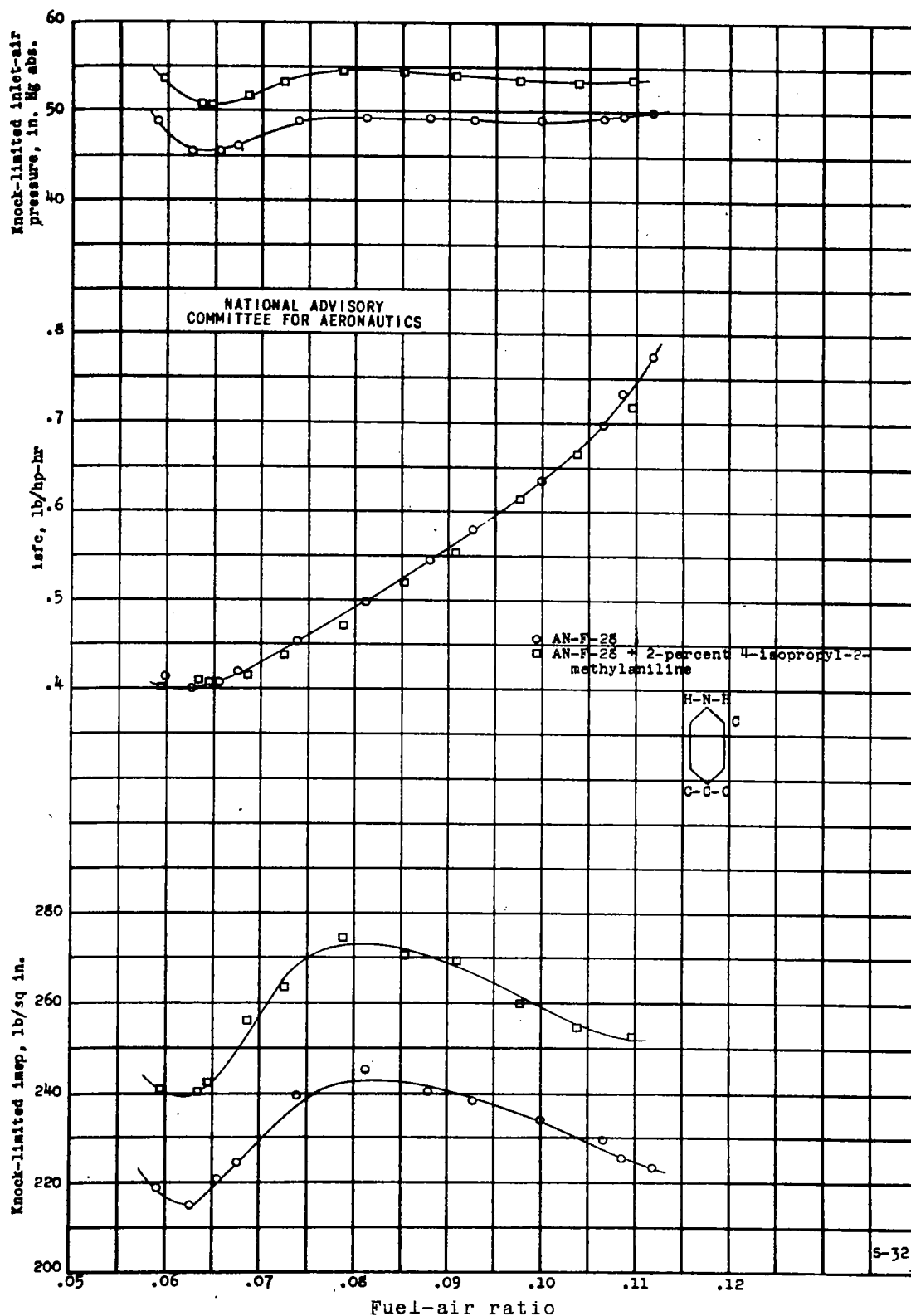
Figure 11. - Effect of addition of 2-percent 4-isopropyl-2-methylaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.





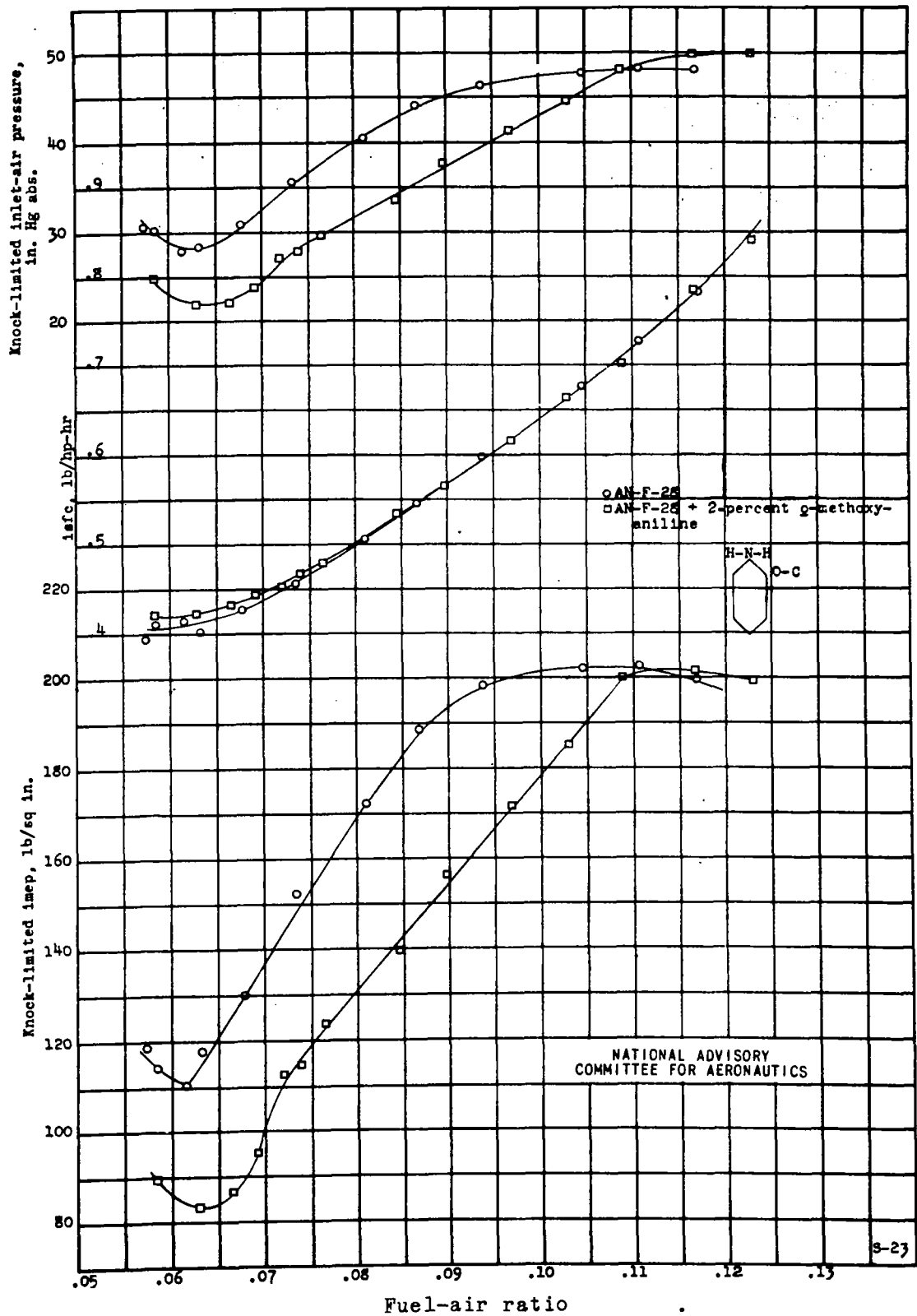
(b) Inlet-air temperature, 250° F; spark advance, 30° B.T.C.; coolant temperature, 250° F.

Figure 11. - Continued. Effect of addition of 2-percent 4-isopropyl-2-methylaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



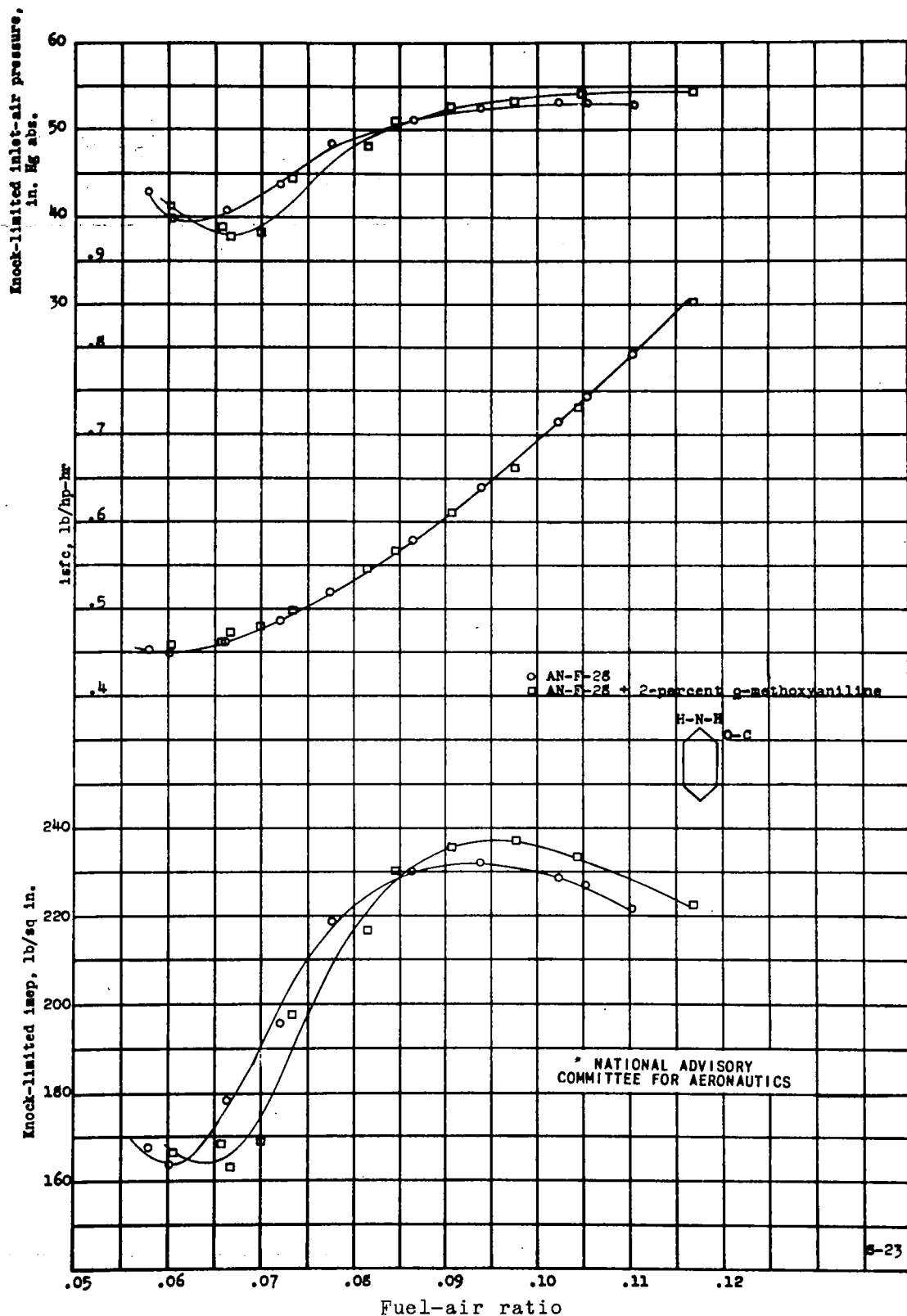
(c) Inlet-air temperature,  $150^{\circ}\text{F}$ ; spark advance,  $30^{\circ}\text{B.T.C.}$ ; coolant temperature,  $250^{\circ}\text{F}$ .

Figure 11. - Concluded. Effect of addition of 2-percent 4-isopropyl-2-methylaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature,  $165^{\circ}\text{F}$ .



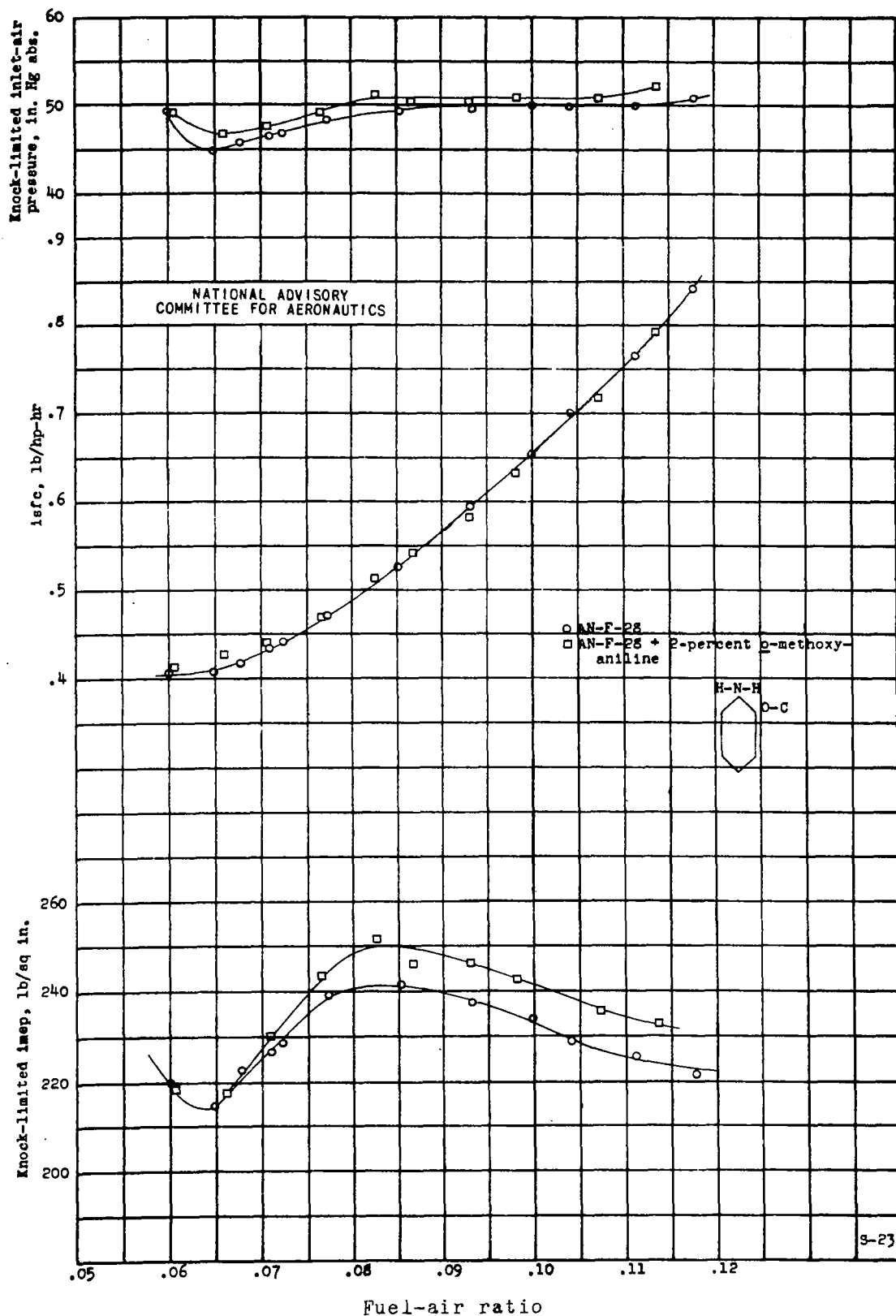
(a) Inlet-air temperature, 225° F; spark advance, 45° B.T.C.; coolant temperature, 375° F.

Figure 12. - Effect of addition of 2-percent g-methoxyaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



(b) Inlet-air temperature, 250° F; spark advance, 30° B.T.C.; coolant temperature, 250° F.

Figure 12. - Continued. Effect of addition of 2-percent g-methoxyaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature, 165° F.



(c) Inlet-air temperature,  $150^{\circ}\text{F}$ ; spark advance,  $30^{\circ}\text{B.T.C.}$ ; coolant temperature,  $250^{\circ}\text{F}$ .

Figure 12. - Concluded. Effect of addition of 2-percent *p*-methoxyaniline to AN-F-28 fuel on knock-limited performance of a CFR engine. Engine speed, 1800 rpm; compression ratio, 7.0; oil temperature,  $165^{\circ}\text{F}$ .

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